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APPLICATION GUIDE FOR ELECTRICAL RELAYS FOR AC SYSTEMS

PART IX RELAYS FOR BUS BAR PROTECTION

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APPLICATION GUIDE FOR ELECTRICAL RELAYS FOR AC SYSTEMS

PART IX RELAYS FOR BUS BAR PROTECTION

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Indian Standard
APPLICATION GUIDE FOR ELECTRICAL RELAYS FOR AC SYSTEMS
PART IX RELAYS FOR BUS BAR PROTECTION

0. FOREWORD

0.1 This Indian Standard (Part IX) was adopted by the Indian Standards Institution on 28 January 1977, after the draft finalized by the Relays Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 Modern power systems are designed to provide uninterrupted electrical supply, yet the possibility of failure cannot be ruled out. The protective relays stand watch and in the event of failures, short-circuits or abnormal operating conditions, help de-energize the unhealthy section of the power system and restrain interference with the remainder of it and thus limit damage to equipment and ensure safety of personnel. They are also used to indicate the type and location of failure so as to assess the effectiveness of the protective schemes.

0.3 The features which the protective relays should possess are :

a) reliability, that is, to ensure correct action even after long periods of inactivity and also to offer repeated operations under severe conditions ;

b) selectivity, that is, to ensure that only the unhealthy part of the system is disconnected;

c) sensitivity, that is, detection of the short-circuit or abnormal operating conditions;

d) speed to prevent or minimize damage and risk of instability of rotating plant; and

e) stability, that is, the ability to operate only under those conditions that call for its operation and to remain either passive or biased against operation under all other conditions.

0.4 This guide has been prepared mainly to assist protection engineers in application of relays installed as a separate unit for protection of bus bar. Few practical examples have also been included to illustrate the application of these relays. However, it is emphasized that this guide has been prepared to assist rather than to specify the relay to be used. This guide deals only with the principles of application of bus bar protection and does not deal with the selection of any particular protective scheme.

0.5 In the preparation of this guide considerable assistance has been derived from several published books and from manufacturers' trade literature. Assistance has also been rendered by State Electricity Boards in collecting actual examples.

0.6 This guide is one of the series of Indian Standard application guides for electrical relays for ac systems.

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1. SCOPE

1.1 This guide (Part IX) deals with application of relays for bus bar protection covered by IS : 3231-1965*.

1.2 This guide does not cover the principles of system design and system protection.

2. TERMINOLOGY

2.1 For the purpose of this guide, the definitions given in IS : 1885 (Part IX)-1966† and IS : 1885 (Part X)-1968‡ shall apply.

3. GENERAL

3.1 **Introduction**-The provision of a separate scheme of protection covering the bus bar zone (bus zone), as distinct from circuit protection relays providing a measure of protection against bus zone faults is widespread at the present time, due to :

a) possibility of widespread disturbance to system as a result of high fault levels on present day systems, and
b) possibility of better utilization of bus arrangements.

3.2 **Causes of Bus Zone Faults**-The more usual causes of bus bar faults may be:

a) deterioration of insulating materials;
b) flashover of insulators due to lightning or system overvoltages;
c) wrong application of or failure to remove temporary earth connections;
d) dropping of jumper connections across bus bars in outdoor installations;
e) short circuits caused by birds, monkeys, vermin and the like; and
f) short circuits caused by construction machinery.

4. BUS ZONE PROTECTION BY CIRCUIT PROTECTION RELAYS

4.0 Before proceeding to the typical bus zone protection schemes, the protection afforded by circuit protection relays against bus zone faults is briefly explained in 4.1 and 4.2.

*Specification for electrical relays for power system protection.
†Electrotechnical vocabulary: Part IX Electrical relays.
‡Electrotechnical vocabulary: Part X Electrical power system protection.

4.1 Overcurrent Back-up- Consider a typical case shown in Fig. 1 where a bus bar has connected to it two outgoing circuits and the low voltage side of two transformer circuits. Assuming power infeed being possible to the bus only through the transformers, the overcurrent relays *51B* on the transformer low voltage side provide a measure of bus bar protection. The disadvantage of such protection is its relatively slow speed.

4.2 Distance Back-up — Consider a typical case shown in Fig. 2, where the bus bar section has a generator-t circuit and a feeder connected to it. Bus wne faults are covered by the following distance protection:

a) The second zone of the distance relays *21LB* at the, far end of the feeder, operating in zone 2 time, and

b) The generator back-up distance relay 21 G, operating after preset time delay.

The limitations of the scheme are long operating time and poor discrimination or selectivity.

5. BUS ZONE PROTECTION SCHEMES

5.0 Categories **of Bus Zone Protection Schemes** — Bus zone protection schemes can be classified into two main categories, namely:

a) those for use with indoor metalclad switchgear installations, and

b) those for use with outdoor or open type installations.

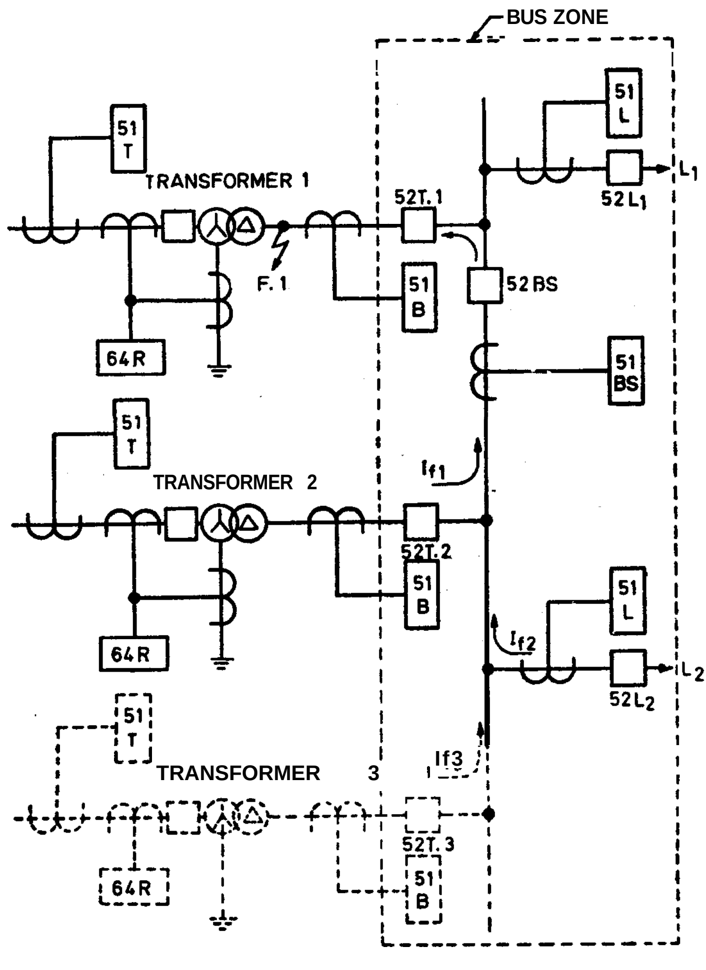
5.1 Schemes for **Indoor Metalclad** Installations

5.1.1 These schemes make use of frame leakage principle, which takes advantage of the fact that such installations are completely metal-enclosed, the enclosure being at earth potential. Metal-enclosed or metalclad switchgear are so constructed that phase-to-phase faults are less likely to occur than phase-to-earth faults and these schemes therefore afford an economical way of protection against phase-to-earth faults.

Where it is considered inadequate to cater to earth faults only and where better discrimination is desired, recourse shall be taken to the schemes described later for outdoor installations under 6.

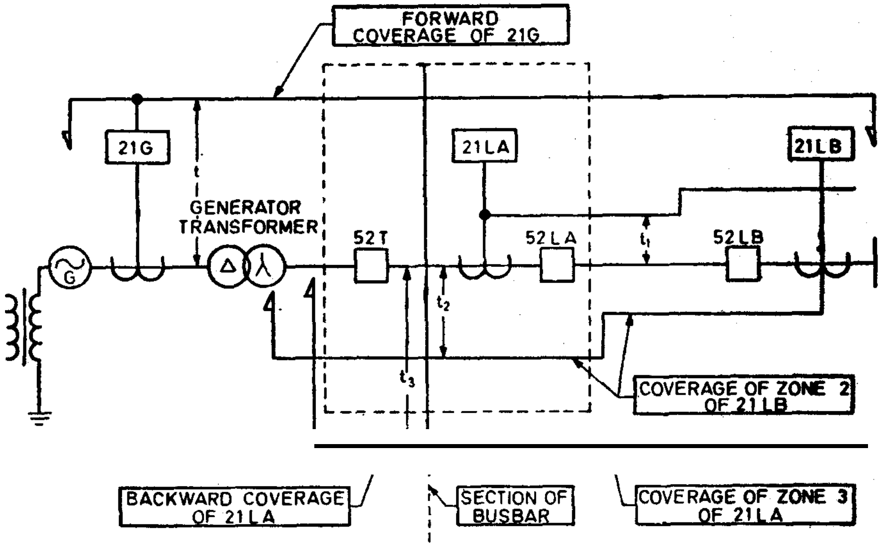
5.1.2 *Earth Leakage Principle* — *The* switchgear metal enclosure or framework is lightly insulated from earth and from the sheaths and armouring of power and control cables as well as conduit connections. The enclosures of the units are housed together and connected to earth at one point through the primary of a current transformer. The secondary of the current transformer feeds an instantaneous overcurrent relay which, when operated, disconnects all the circuits connected to the bus bar. Principle of earth leakage protection is shown in Fig. 3.

5.1.3 *Check Feature -A* check feature should be incorporated to prevent mal-operation of the protection. This check feature measures the zero-sequence current flowing from the bus bars or the zero-sequence voltage of the bus bars and can take any one of the following forms:



64R — Restricted Earth Fault Protection for Transformer KV
51 *T* — Transformer HV Over-Current Back-up Relay (IDMTL)
51B — Bus Bar Back-up Over-Current Relay (IDMTL)
51L — Line Protection Relay (IDMTL)
SIBS-Bus Section Protective Relay (IDMTL)
52 — Circuit Breaker

FIG. 1 INSTANCES OF MAL-OPERATION OF BUS BAR BACK-UP. IDMTL OVER-CURRENT RELAY (TYPICAL)



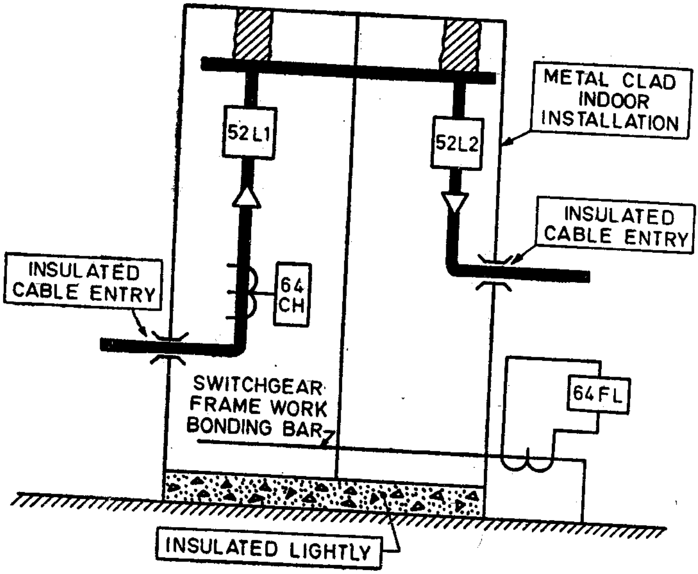
21LA, 21LB — **Line Distance Protection**
21G — **Generator Back-up Distance Protection**
t_1 — **Zone 1 Time Setting of *21LA,* 21LB**
t--Time Setting of *21G*
t_2 **---Zone 2 Time Setting of *21LA, 21LB***
t_3 — **Zone 3 Time Setting of *21LA, 21LB***
52 — **Circuit Breaker**

FIG. 2 DISTANCE BACK-UP FOR BUS BARS (TYPICAL)

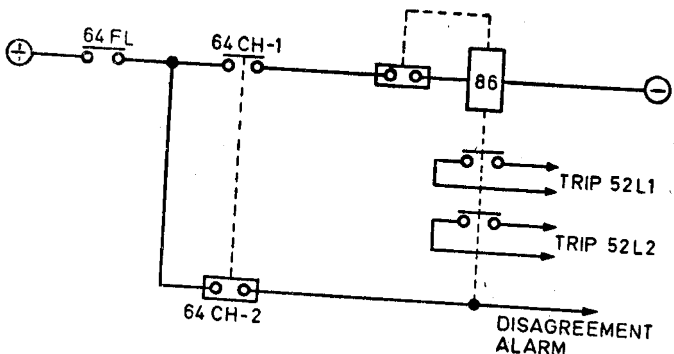
a) Core-balance current transformer slipped over each feeder circuit connected to the bus bars and capable of feeding zero-sequence currents, the secondaries of all such core-balance current transformers being paralleled, to another instantaneous overcurrent relay (*see* Fig. 4A).

b) A set of three current transformers on each of such circuits as in 5.1.3(a), residually connected and secondaries paralleled and connected to the relay (see Fig. 4B).

c) Current transformers in the neutrals of all the windings of the power transformer in the station connected to the bus bars, these current transformers being paralleled to the relay (*see* Fii. 4C). Alternatively, if paralleling of current transformers as required in 5.1.3 (a), 5.1.3(b) and 5.1.3(c)is not possible, one relay per fault feeding circuit with their contacts in parallel can also be used.



3A AC Circuit



3B DC Circuit

64CH — Check Relay
64FL — Frame Leakage Relay
86 — High Speed Relay
52 — Circuit Breaker

FIG. 3 PRINCIPLE OF FRAME LEAKAGE PROTECTION

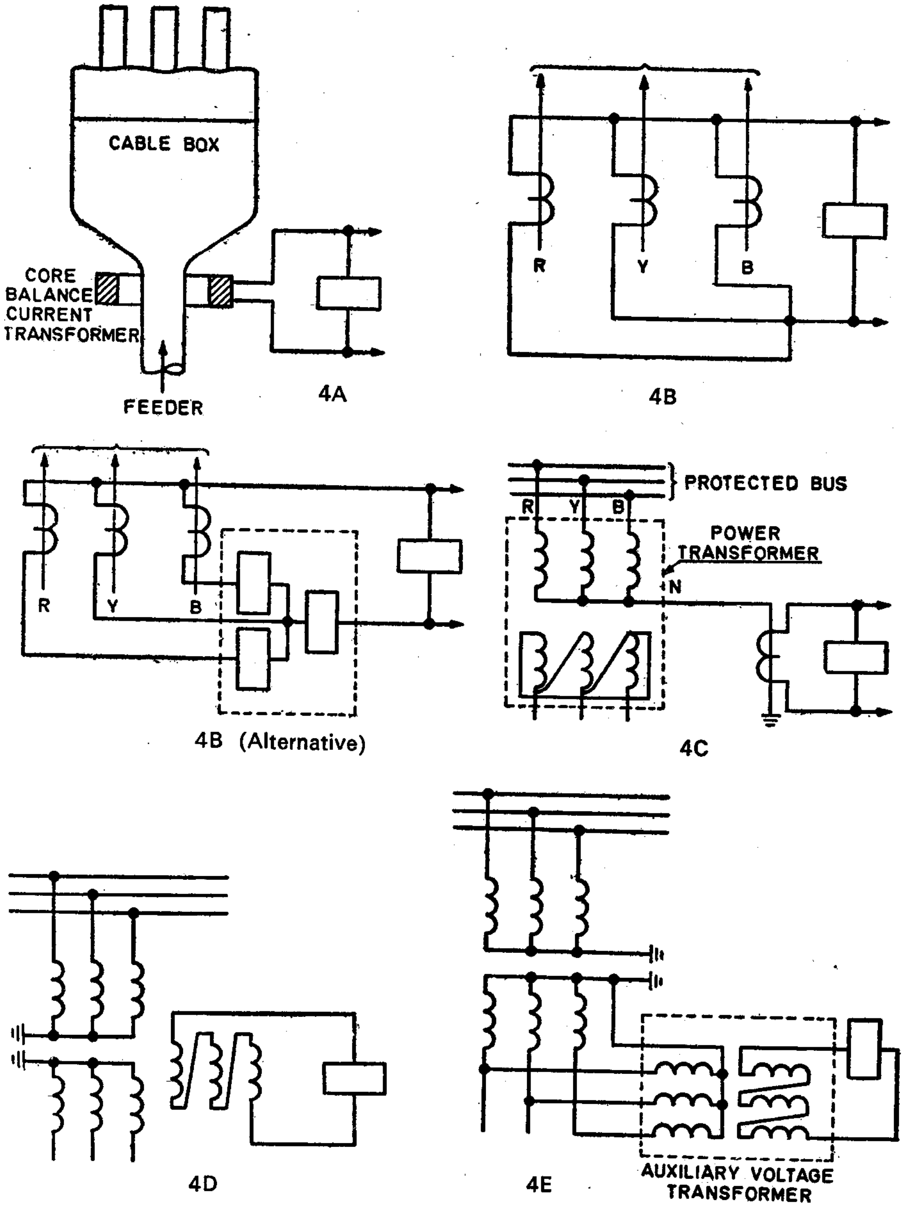


FIG. 4 METHOD OF ENERGISING CHECK RELAY FOR FRAME LEAKAGE, PROTECTION (TYPICAL)

d) A voltage operated relay connected across the broken delta winding of a voltage transformer connected to the bus bars (*see* Fig. 4D or Fig. 4E). The contact of the check relay is connected in series with that of the earth leakage relay, as in Fig. 3B. In method **5.1.3**(c) above, the check feature is inoperative, when the transformer circuits are disconnected. Also none of the above methods are restricted, that is, they would operate for faults anywhere in the system. Hence, the check relays should have self reset contacts. If the check feature, as above, cannot be provided at all, the instantaneous over-current relay of 5.1.2 should be replaced by an IDMTL relay to avoid mal-operation on short-lived spurious *currents.*

5.1.4 A typical example of a single bus bar installation is given in Fig. 5A. The switchboard has a switchgear bonding bar, bonding all the framework 'together and a cable bonding bar. It is insulated from the framework and is connected to the station earth. The primary of the earth leakage current transformer connects these two bars. The secondary of this current transformer feeds the instantaneous overcurrent relay *64FL*, which is usually of the attracted armature type. The check relay 64CH is shown connected to a core-balance current transformer mounted on the incoming feeder. When both 64CH and 64FL are operated, a hand reset master trip relay 86FL is energised (see Fig. 5B) which trips the various feeders and also gives an alarm. A disagreement alarm is also sounded when the relay 64FL operates.

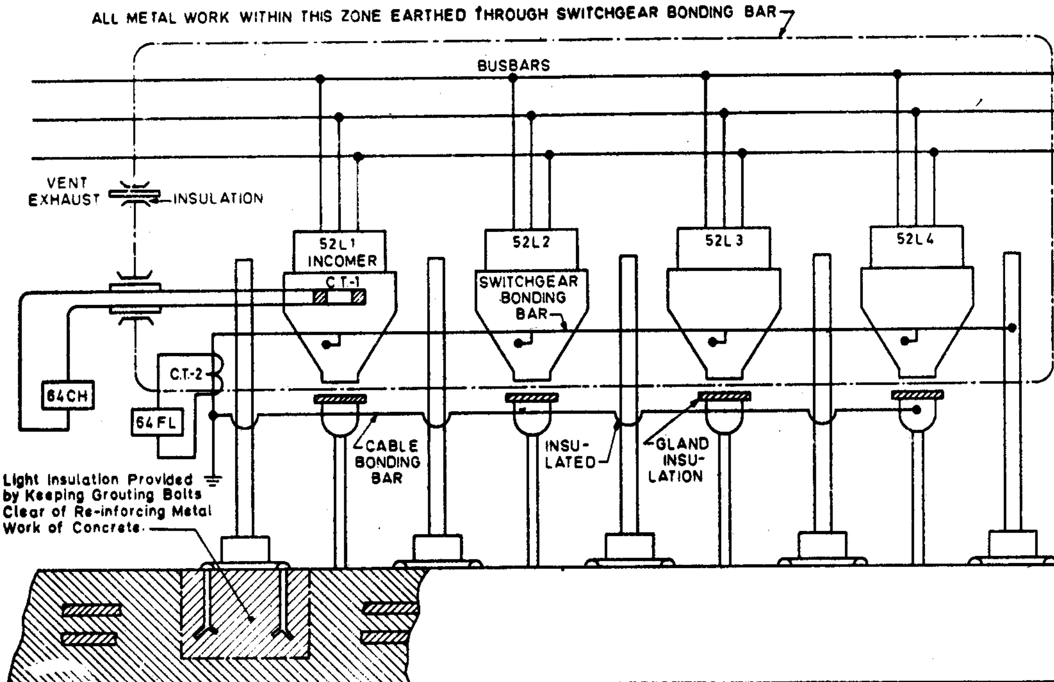
5.1.5 *Application to Sectionalised and Duplicate Bus Bars* — The frame leakage "principle can be applied to sectionalised or duplicate bus bar installations also.

5.1.5.1 Its application to a sectionalised bus bar is given in Fig. 6, where the section to the left of the bus section breaker,. the section to the right of the bus section breaker and the section contammg the bus section breaker *52E*, form the three zones *A*, *B* and C respectively. Here, it is necessary to provide insulation between the zones in addition to insulating the switch-board from earth, each zone having its own switchgear bonding bar is connected to the cable bonding bar through the primary of frame leakage current transformer, the current transformer of zone C having two secondaries (alternatively two separate current transformers can be used). The ratios of all the current transformers should be the same. A single relay 64FLA is provided for zones *A* and C and another relay *64FLB for zones B* and C energised as shown. A common check relay 64CHserves all the three zones.

A fault in zone *A* is cleared by the tripping of all breakers in zone *A* plus *52E*. Likewise a fault in zone *B* is cleared by the tripping of all breakers in zone *B* plus *52E*. A fault in zone C is cleared by the tripping of all breakers in zones *A*, *B* and C.

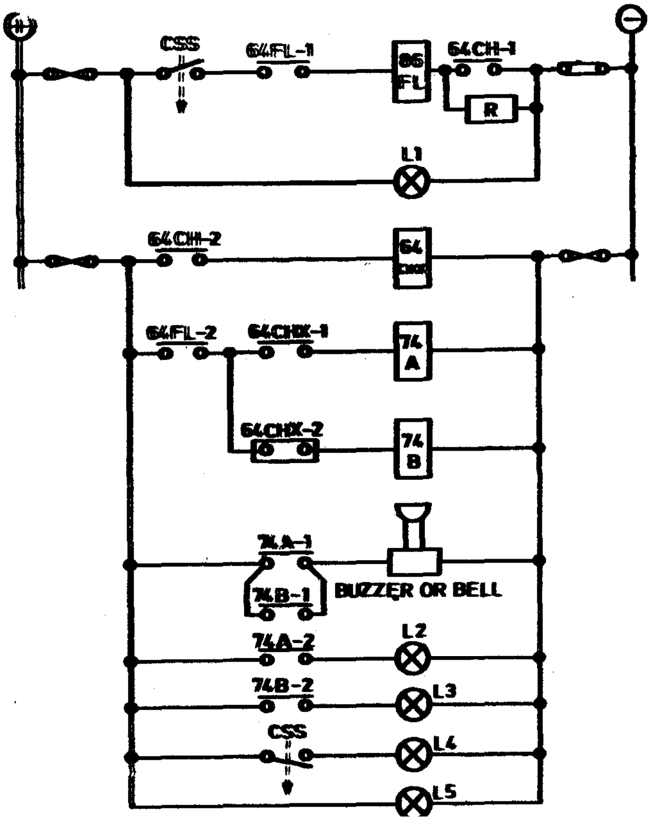
5.1.5.2 As a variation to the scheme described in 5.1.5.1 the bus section breaker may be included in one of the zones *A* or *B*, as shown in Fig. 7.

Faults in zone *A are* cleared by tripping all breakers in zone *A* plus 52E.



5A Diagrammatic

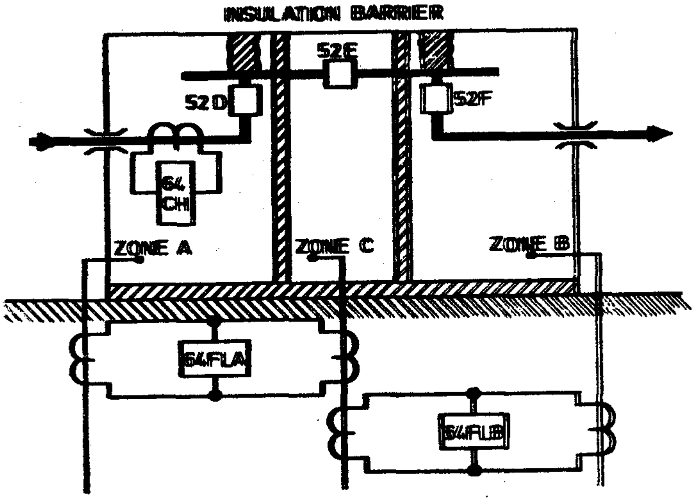
FIG. 5 TYPICAL SINGLE BUS BAR FRAME LEAKAGE PROTECTION INSTALLATION — *Contd*



5B Schematic

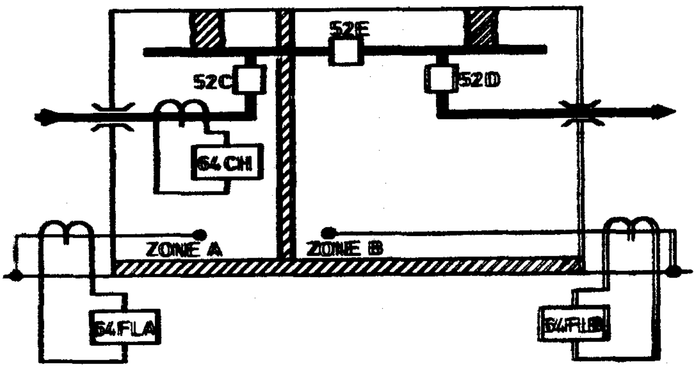
64CHX — Auxiliary Relay for *64CH*
86FL — Trip Relay for *64FL*
74A — Alarm Relay for Genuine Bus Bar Faults
74B — Alarm Relay for Spurious Frame Leakage Relay Operation
L1 — Lamp Indication — Bus Bar Protection Trip Supply Healthy
L2 — Lamp Indication — Bus Bar Fault
L3 — Lamp Indication — Frame Leakage Relay Mal-Operated
L4 — Lamp Indication — Bus Bar Protection Out
L5 — Lamp Indication — Bus Bar Protection Alarm Supply Healthy
CSS — Control Selector Switch (Protection in — Protection out)

Fig. 5 Typical Single Bus Bar Frame Leakage Protection Installation



52E — Bus Section Breaker
52D, *52F* — Feeder Circuit Breakers
64CH — Check Relay
64FLA — Zone A: Frame Leakage Relay
64FLB — Zone B: Frame Leakage Relay

FIG. 6 FRAME LEAKAGE PROTECTION FOR SECTIONALIZED BUS BAR, SCHEME 1 (TYPICAL)



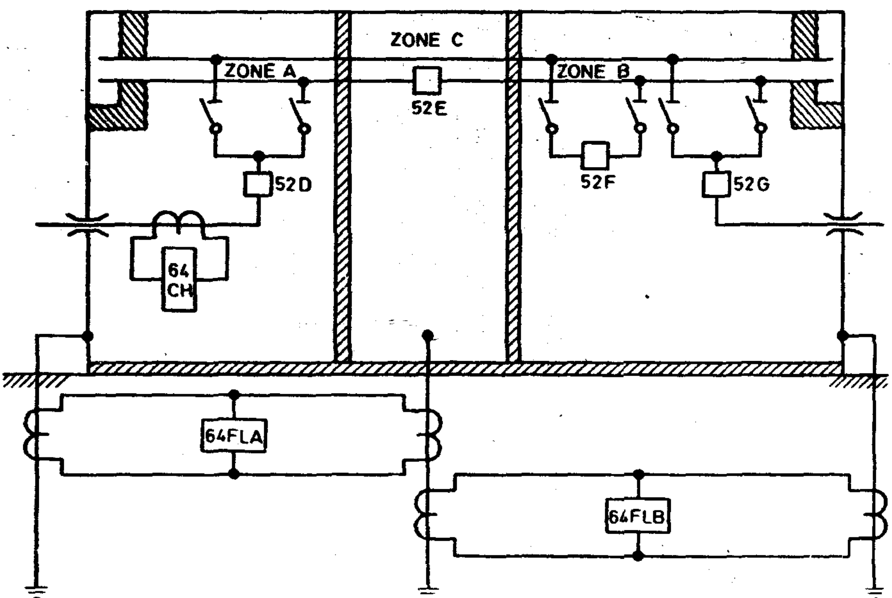
52E — Bus Section Breaker
52C, *52D* — Feeder Circuit Breakers
64CH — Check Relay
64FLA — Zone A: Frame Leakage Relay
64FLB — Zone B: Frame Leakage Relay

FIG. 7 FRAME LEAKAGE PROTECTION FOR SECTIONALIZED BUS BAR, SCHEME 2 (TYPICAL)

Faults in zone *B are* cleared by tripping of all breakers in zone *B* plus *52E.* Faults occurring between the barrier and *52E* are cleared by zone *B* protection intertripping zone *A,* through a timer with a delay of 0·4 to 0·5 seconds. A limitation is that there should be an earthed source of supply in the zone not containing the bus section breaker (zone *A in* Fig. 7). In installations with more than one bus section breaker the earthed sources of supply shall he so arranged that under all switching conditions a fault between any bus section breaker and the nearest barrier is always fed.

515.3 This protection applied to duplicate bus bars is shown in Fig. 8, where the arrangement is similar to that shown in Fig. 6. The bus coupler breaker is included in one of the zones (zone *B).*

Faults in zone *A are* cleared by tripping all breakers in zone *A,* plus the bus section and bus coupler breakers, plus all breakers connected to the reserve bus, leaving only the circuits connected to the zone *B.* Faults in zone C isolate the switchboard completely.



52D, 52E, 52F, 52G — Circuit Breaker
64CH — Check Relay
64FLA -Zone A: Frame Leakage Relay
64FLB — Zone B: Frame Leakage Relay

FIG. 8 FRAME LEAKAGE PROTECTION APPLIED TO DUPLICATE BUS BARS (TYPICAL)

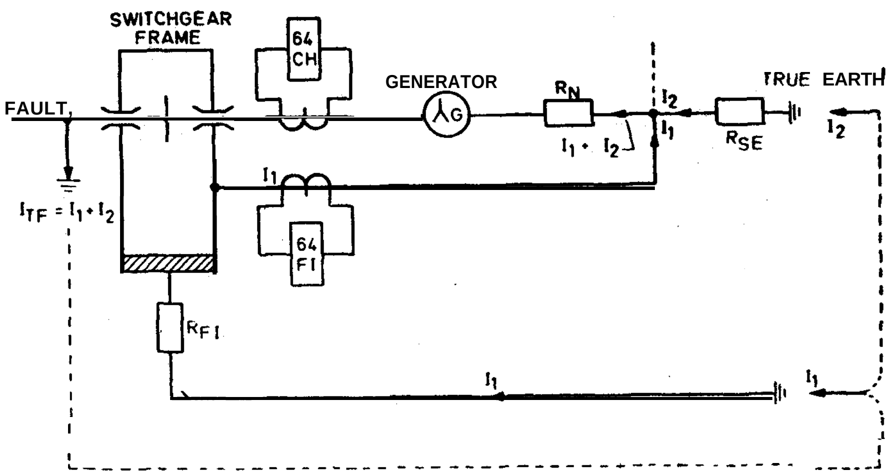
5.1.6 Setting

Let I_{TF} = maximum through fault current,
I_F = minimum internal fault current,
R_{SE} = resistance of the station earthing electrodes,
R_{FI} = switchgear frame insulation resistance,
N = ratio of earth leakage current transformers, and
I_{POC} = minimum primary operating current.

Then, from Fig. 9 it can be seen that to prevent mal-operation on through faults,

$$I_{POC} > I_{TF} \frac{R_{SE}}{R_{SE}+R_{FI}}$$

For reliable operation under minimum internal fault conditions, I_{POC} should be generally of the order of $0{\cdot}3\,I_{TF}$. The current transformer ratio N, is so chosen that a setting within the relay range is retained for a current corresponding to $\frac{0{\cdot}3\ I_{TF}}{N}$. It will be seen, that I_{POC} can be reduced, by providing better insulation between framework and earth.



I_{TF} — Through Fault Current
I_1 — Leakage Current through Frame Insulation on through Earth Faults
I_2 — Ground Return Current
R_{FI} — Switchgear Frame Insulation Resistance
R_{SE} — Resistance of Station Earthing Electrodes
R_N — Neutral Earthing Resistance
(For Resistance Earthed System only)
64CH — Check Relay
64FL — Frame Leakage Relay

FIG. 9 MAL-OPERATION OF FRAME LEAKAGE PROTECTION UNDER THROUGH FAULTS (TYPICAL)

5.1.6.1 *Operating time* — An overall operating time of the order of 3 cycles can be obtained, at fault current of 5 times the setting.

5.1.7 *Application Notes*

5.1.7.1 *Switchgear framework insulation*

a) If the switchgear is mounted on concrete foundation, no special insulation is required provided it is ensured that at least 50 mm thickness of concrete is available between each grouting bolt and surrounding metalwork like reinforcing bars.

b) If the gear is mounted on steel channels, special insulation should be provided between the channels and framework.

c) All metalwork leading away from the gear such as vent exhausts, conduits, shall be fitted with insulated joints as near to the gear as possible.

d) If any high tension line enters the gear through bushings, the bushing support flanges should be insulated from the framework of the gear and earthed separately.

e) The clearance between the switchgear framework and secondary structural steel work should not be less than 50 mm.

f) The overall frame insulation to earth should have a minimum resistance of 3 to 10 ohms, the higher figure should be aimed at, when the earth electrode resistance is comparatively high and the frame leakage relay is very sensitive. Mal-operation can otherwise occur on through faults since check feature is not of the restricted type.

g) Glands of all main and auxiliary cables entering the gear should be insulated from the switchgear framework by insulating sleeves or washers. The glands of the power cables should have an insulation to withstand 8 to 10 kV.

5.1.7.2 *Insulation between zones*—At the junction of two zones an insulated band joint shall be used and all conduits, vent-heaters and metal connections shall be made with insulating inserts.

5.1.7.3 *Earthing of switchgear*

a) All the metal framework of the switchgear panels and cable boxes in a zone shall be connected to a common switchgear bonding bar. The switchgear bonding bars of zones should be insulated from one another.

b) If the cable sheaths are earthed at the station, all the cable glands and sheaths should be solidly connected to a cable bonding bar which should be insulated from the switchgear framework and connected directly to the station earth.

c) Where earthing devices are used for feeder earthing, this should be connected to the cable bonding bar.

d) The secondary circuits such as current transformer neutrals, if

earthed within the protected zone, for example in the instrument panels of drawout metalclad gear, should be earthed to the cable bonding bar. In cases where an earth connection exists between equipment and the switchgear framework, for example the Y-phase of the voltage transformer secondary, no further earthing of such circuits should be made to the cable bonding bar.

e) The earthing of all instrument, meter and relay cases should be done to the switchgear framework to avoid risk of shock to operating personnel.

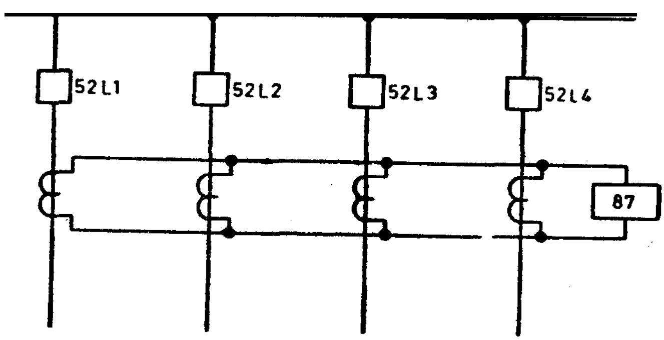
f) The cable bonding bar should be connected to the station earth through the main station earth electrode and not through a separate electrode, to avoid inclusion of additional earth resistance in the earth path.

g) In case of resistance earthed systems the cable bonding bar should be connected to the station earthing electrode, so as not to include the neutral resistance in the earth path.

5.2 Schemes for Outdoor Installation

5.2.1 The principle of frame leakage can be applied to outdoor installations as well, where the bases of all support insulators are lightly insulated from the gantries and are connected together and earthed through the primary of an earth leakage current transformer. The scheme does not provide protection against phase faults and the obvious difficulty of properly insulating all the support insulators which may include insulations of equipment such as isolators, makes the application of such a scheme unsatisfactory.

5.2.2 The differential principle using the current or voltage balance arrangement is in most common use for providing bus zone protection. The principle is given in Fig. 10 which shows four circuits connected to breakers.



87 — *Differential Relay*
52L1, 52L2, 52L3, 52L4 — Feeder Circuit Breakers

FIG. 10 DIFFERENTIAL PRINCIPLE

Current transformers in each circuit are connected in current balance arrangement to feed a differential relay. Under healthy or external (throughbj fault conditions when the sum of the currents measured by the current transformers is zero, no current passes through the relay. A fault on the bus bars, on the other hand, produces a current through the relay which picks up and causes disconnection of the bus bar from the system thus isolating the fault. The protected zone is the area bounded by the current transformers.

5.2.3 Successful application of this principle calls for current transformers with characteristics such that a current in the relay is produced only for internal fault conditions and not under healthy or external fault conditions. However, the causes of current through the relay under such conditions can be classified as follows:

a) At a certain excitation voltage, the different current transformers can draw different magnetising currents causing a spill current to flow through the relay.
b) In bus zone differential schemes, the currents through the primaries of all the current transformers may not be the same under through fault conditions and this would also cause different magnetising currents to be drawn causing a spill current to flow in the relay.
c) The lead burden between the current transformer and the relay may be different for the different current transformers causing unequal loading of the current transformers again resulting in spill currents due to different magnetising currents.
d) Depending upon the instant of fault, the fault current can contain varying proportions of unidirectional transients. The *X/R ratio* of the system up to the fault point determines the time constant of this transient. High values of such transients can cause saturation of the current transformers resulting in the current balance being upset.
e) The cores of the current transformers can have remanent magnetism, due, for example, to previous fault currents. Depending upon its magnitude and polarity ac fault currents can cause saturation, leading to unbalance.

5.2.4 The limitations mentioned in 5.2.3 can be overcome by the following methods:

a) Use of current transformers without the ferrous cores (called linear couplers) thereby- eliminating the cause of varying magnetising currents and saturation,
b) Use of medium/high impedance differential relays,
c) Use of biased differential relays, and
d) Use of IDMTL relays.

5.2.5 *Linear Couplers* — The limitations mentioned in 5.2.3 like different magnetising currents and core saturation'are due to the presence of the iron

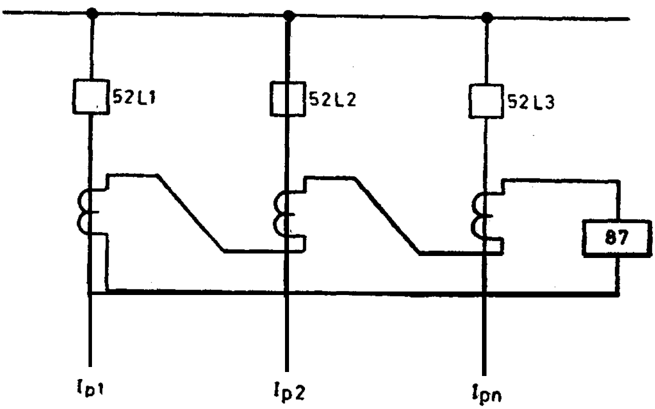
core which has non-linear characteristics. Current transformers have been developed with air cores, thus eliminating the cause of these limitations.

Linear couplers have non-magnetic cores over which the secondary winding is toroidally wound and uniformly distributed. The absence of *magnetic* core limits the output of linear couplers to about 3 VA for every I 000 A primary current. Linear couplers have poor response to transient currents which consequently undergo considerable attenuation. Special filters to block dc components from entering the relay are therefore eliminated.

Scheme using linear couplers usually employ the voltage balance principle which is shown in Fig. 11. If $I_{p1}, I_{p2} \ldots . I_{pn}$ are the primary currents in the various circuits and M *is the* mutual reactance in ohms (assumed the same for all the couplers), then the voltage developed across the relay,

$$V = I_{p1}M + I_{p2}M + \ldots . I_{pn}M$$
$$= M \left(I_{p1} + I_{p2} + \ldots . I_{pn}\right)$$

For external faults where $I_{p1}+I_{p2}+\ldots . I_{pn}=0$, no voltage is produced across the relay. During internal faults, a resultant voltage is impressed upon the relay. A high impedance, low watt consumption (5 mW or less) voltage operated relay is employed. Linear couplers are essentially voltage sources, the current in the secondary loop being limited by the self impedance of the coupler, the relay impedance and the lead impedance, the latter being usually negligible compared to the other two. Linear couplers are made with mutual impedances accurate to within ± 1 percent and this determines the stability ratio of the protective system which is defined as:



I_{p1}, I_{p2}, I,, — Primary Currents
52L1, 52L2, 52L3 — Feeder Circuit Breakers
87 — Differential Relay

FIG. 11 USE OF LINEAR COUPLER (TYPICAL)

$$\text{Stability ratio} = \frac{\text{The maximum external fault current for non-operation}}{\text{The minimum internal fault current for Operation}}$$

The stability ratio is calculated as follows taking the worst case as that with positive error in the 'Fault coupler' and negative error in the 'Source coupler'.

The voltage developed by the couplers for the minimum internal fault! current $I'_f = MI'_F$

The maximum error voltage developed from an external fault current $I_F = 0{\cdot}02\ MI'_F$

For nonoperation of the relay under external fault, $0{\cdot}02\ MI_F < MI'_F$.

$$\frac{I_F}{I'_F} \leqslant 50$$

Taking a safety factor of 2, this gives a stability ratio of as high as 25,

5.2.6 *Balanced Current Systems* — Consider the circuit of Fig. 12A CT_1 and CT_2 are assumed to be identical current transformers having identical parameters like ratio, resistance and similar magnetising characteristics. Under normal conditions, therefore, they share the burden in a manner illustrated in Fig. 12B. The emfdevelopcd by the current transformers are, therefore, equal. Points 'XX', '*YY*', etc, are equipotential points along the pilots and no current will flow if these are short-circuited say? through a low impedance relay. However, in practice such equipotential points are sometimes difficult to obtain conveniently, and it may be required to connect the relays across non-equipotential points like 'Z-Z_1'. When such points are bridged by a low-impedance device an equilising current will flow through it, reducing the potential difference across them to zero. The voltage drop around the loop before and after the shorting is shown in Fig. 12C and it will be seen that one of the current transformers (CT_2) has' to develop an increased voltage compared to the *other*. The CT_1 being assumed to be perfect and identical the circulating current (i) between them will still balance. Thus the output of CT_2 is increased to E_{21} and that of CT_1 is decreased to E_{11}.

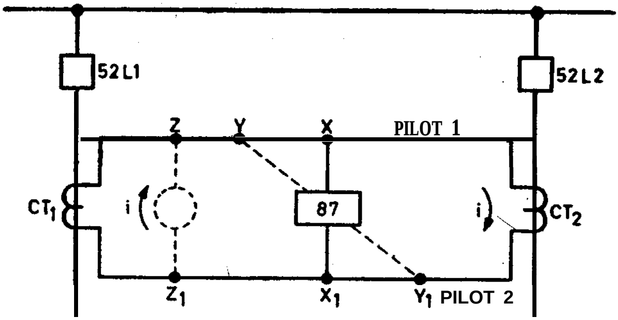
If, under the above conditions a through fault of high magnitude were to occur! the burden of CT_2 can be excessive and drive it into saturation, resulting in a current through the relay and causing ma&operation.

Increasing the relay setting to avoid this trouble is not desirable as it increases the primary operating current, This is particularly true for high speed relays whose settings should take into account the effect of primary current transients *also*. To a certain extent this can be applied to low speed relays.

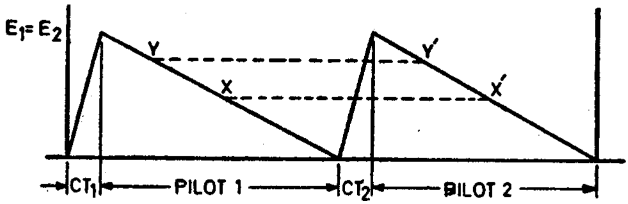
Padding resistors can *also* be introduced in the interconnecting wiring to equalise the burdens. But this method only serves to increase the burdens on the less-loaded current transformers.

5.2.7 *High/Medium Impedance Relays*

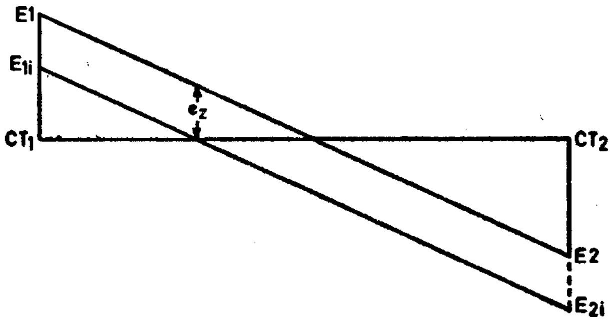
5.2.7.1 The basic *circuit is* given *in* Fig. 13 and it will be seen that the



12A Basic Balanced Current Circuit



12B Voltage Distribution Around the Loop



12C Effect of Relay Connection at Non-Electrical Midpoint

CT_1, CT_2 — Current Transformers
52L1, 52L2 -- Circuit Breakers
87 -- Differential Relay
E1 . . ., E2 — Generated emfs of CT_1 and CT_2
e_z — Voltage across relay under load conditions when connected across Z-Z1

FIG. 12 BALANCED CURRENT SYSTEMS (TYPICAL)

scheme is similar to that of Fig. 12 except that the relay circuit has a high impedance *R* which may be an external impedance or may be inherent in the relay coil. Even if the points J_1 and J_2 across which the relay is connected are non-equipotential points, very little current flows through the relay because of its high impedance. Under healthy conditions, therefore, the current transformers work as if there is an open circuit between points J_1 and J_2. The circulating currents in the loop and the current transformer working voltages are not materially disturbed.

5.2.7.2 Under *external fault conditions* — Refer to Fig. 13 and consider a through fault at F_2. Neglecting the effect of load, if all current transformers behave ideally the voltage between points J_1 and J_2 will be zero or will be of a small value depending upon whether these two points are the electrical mid-points or not. If however, the fault current transformer due to its being loaded more compared to the source current transformer is driven into saturation its generated voltage *E2* will be reduced. Depending upon the degree of saturation this can be partial (*E2*) or total (zero). In the worst case of total saturation in the fault current transformer and none in the source current transformer, the latter forces the current through the 'dead' impedance of the fault current transformer, which is assumed to be mainly resistive. Consequently a voltage e3 appears across the junction points J_1 and J_2 (and therefore across the relay). For any other assumed condition, such as partial saturation in source current transformers and total saturation in fault current transformer, the magnitude of the above voltage is lesser, as can be seen from Fig. 13B.

The value of this voltage can be shown to be equal to the following :

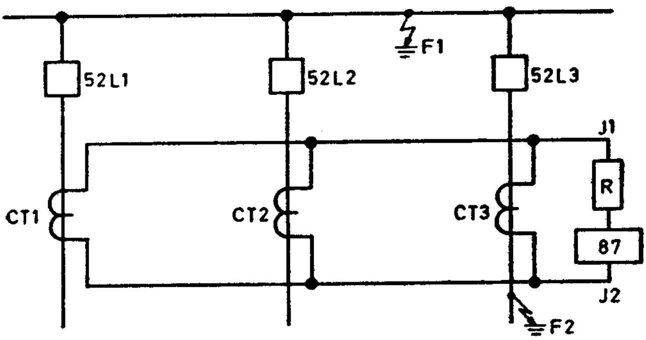
$$V_{rms} = (R_2 + 2r)\frac{I_f}{N} \text{ or}$$

$$V_{rms} = (R_2 + 2r)\, i$$

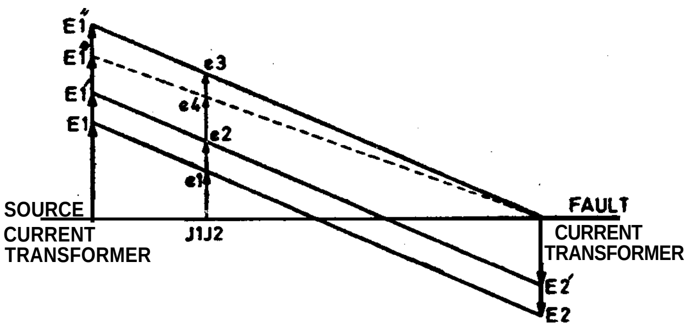
where

V_{rms} = voltage across relay,
R_2 = secondary resistance of fault current transformer,
r = lead resistance between relay and fault current transformer (one way),
I_f = maximum through fault primary current (rms value),
i = secondary equivalent of I_f, and
N = nominal ratio of current transformer.

53.73 Under *internal fault conditions* — The currents delivered by the current transformers have the same polarity with respect to the points J_1 and J_2. The current transformers therefore work into the high impedance of the relay, with high voltages appearing across the current transformer secondaries as well as the relay. The ratio of voltages across the points J_1 and J_2 during internal faults to that during external faults can be as high as 10, this factor providing discrimination between internal and external faults.



13A Principle



13B Relay Setting Voltages

52L1, *52L2*, *52L3* — circuit Breaker
R — High Impedance
87 — Relay
CT1, CT2, CT3 — Current Transformers
e1 — Voltage Across Relay Under Normal Condition When Connected to Non-Electrical Midpoint
e2 — Voltage Across Relay with Partial Saturation in Fault Current Transformer and no Saturation in Source Current Transformer
e3 — Voltage Across Relay with Complete Saturation in Fault Current Transformer and no Saturation in Source Current Transformer
e4 — Voltage Across Relay with Complete Saturation in Fault Current Transformer and Partial Saturation in Source Current Transformer

FIG. 13 HIGH/MEDIUM IMPEDANCE SCHEMES

This is where the main advantage of high impedance relay over the low impedance type exists. In the latter under through fault conditions, if the fault current transformer saturates, the relay shunts more than 90 percent of the secondary current. It cannot therefore differentiate between a through and in-zone fault.

5.2.7.4 *Relay Setting — The* high impedance relay is so set that it does not pick-up for voltages produced across it during through fault conditions. As the through fault value is likely to change with time, as the generation in the system is increased, the relay setting is to be reviewed from time to time. In the initial state when fault levels are low it is desirable to adopt a lower setting.

The sensitivity or the minimum primary operating current for a given relay setting voltage depends on the excitation currents drawn by the various current transformers in parallel with the relay as well as the current drawn by the relay itself at that voltage. If i_r is the current drawn by the relay and I_u the sum of the magnetising current of the current transformers the total minimum secondary current to be supplied by the source current transformer for relay operation can be written as:

$$i_s = (i_r + I_u)$$

The corresponding primary operating current is:

$$I_p = N\,(i_r + I_u)$$

The minimum primary operating current can be reduced by making the relay current as small as possible and using current transformers with lower magnetising currents. The larger the number of circuits (and current transformers in parallel) the larger is the minimum primary operating current.

5.2.8 *Types of High/Medium Impedance Relays-The* three general types are:

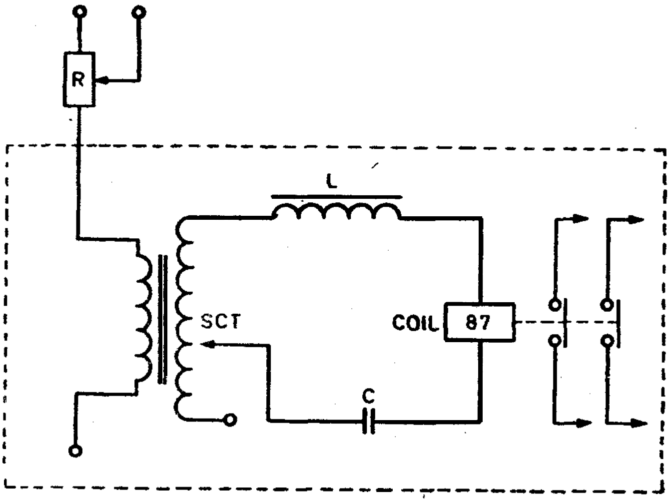
a) Relays using linear resistors in series with their operating coils,

b) Relays using non-linear resistors in series with their operating coils, and

c) Relays using both linear and non-linear resistors.

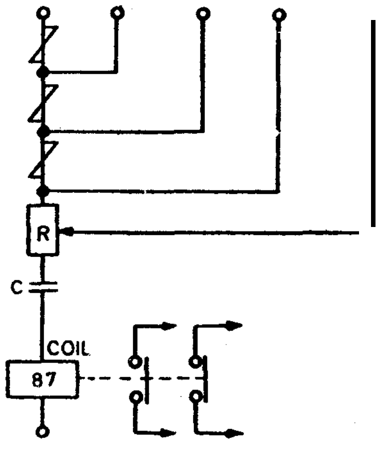
5.2.8.1 *Relays using a linear resistor in series with their operating coil* — A typical relay is shown in Fig. 14. The relay has a low burden current operated coil connected to the secondary of a saturating current transformer through a series tuned circuit. The series tuned circuit makes the relay immune to harmonics and dc transients in the voltage across the relay. The saturating current transformer limits the current in the relay coil to a safe value under heavy current in zone faults. The external linear resistor *R* which is adjustable is connected in series with the relay.

The advantages of this relay are that with linear resistor accurate settings may be made and this being continuously adjustable, a setting equal to the



SCT — Saturating Current Transformer
L and *C* — Tuned Circuit
R — *Linear* Resistor
87 — Relay

FIG. 14 RELAY USING A LINEAR RESISTOR (TYPICAL)



87 — Relay
C -capacitor
R — *Non-Linear* Resistor

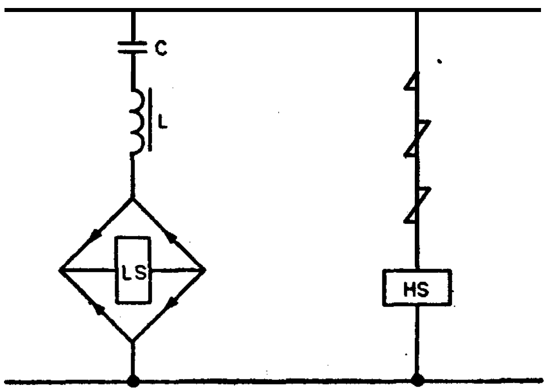
FIG. 15 RELAY USING NON-LINEAR RESISTOR (TYPICAL)

calculated voltage can be chosen. Also the variation of resistor value with temperature is not of consequence.

5.2.8.2 *Relays using a non-linear resistor in series with their operating coil* — A typical relay is shown in Fig. 15. The stabilitising resistor is made up of a series of non-linear resistors chosen by a plug, the lowest step, however, being a variable linear resistor, which limits the maximum relay current to a safe value. The series capacitor tunes out harmonics and blocks direct current. The non-linear resistor follows the law $V = KI^{\alpha}$ (where V is the voltage, I the current and α a characteristic+ of the resistor).. The advantage is that the relay current at pick up can be quite small, the current increasing rapidly for comparatively smaller increases in voltage resulting in fast relay operation. The minimum primary operating current is mainly dependent on current transformer magnetising current.

The disadvantages are that continuous variation in resistor values is not possible and it will not be possible to set the relay to the exact calculated value. The non-linear resistors are rather bulky and expensive, and are susceptible to temperature variations .

5.2.8.3 *Relays using both linear and non-linear resistors-A* typical relay is shown in Fig. 16. The low set unit *LS* consists of a relay connected through a bridge to a series tuning unit *L* and C. The high set unit *HS* is connected across the low set unit and consists of a relay in series with non-linear resistor. The connection of the low set relay through the bridge ensures that variations in the value of the relay resistance for setting purposes will not affect the tuning. Under heavy internal fault conditions the high set unit operates faster because of larger currents through the non-linear resistor.



LS — Low Set Unit
HS — High Set Unit
L and *C* — Tuned Circuit,

FIG. 16 RELAY USING BOTH LINEAR AND NON-LINEAR RESISTOR (TYPICAL)

5.2.8.4 *Limitation of voltage peaks* — With high/medium impedance relays, under internal fault conditions, the current transformers have the same polarity with respect to each other, driving their currents through the high impedance of the relay. This can be considered as practically open-circuit condition. The current transformers can therefore be driven to saturation resulting in high peak voltages across the relay, associated wiring, etc. For values of $V_k = \frac{V_f}{2}$ this peak voltage V_{peak} is given by the following formula:

$$V_{peak} = 2\sqrt{2}\sqrt{V_k (V_f - V_k)}$$

where

V_k = the knee point voltages of the current transformers involved, and

V_f = the maximum rms voltage the current transformer would have developed if there were fault current I_f flowing in the relay circuit,

= I_f X (where X is the impedance of relay branch presented to I_f).

To keep these voltages limited to a safe value, a non-linear resistor is generally connected across the relay so that when the voltage reaches the dangerous value, the non-linear resistor provides an easy shunt path for the current. The voltage limiting resistors are used only if the calculated value of V_{peak} exceeds 3 kV,and it is normal practice to choose resistors that keep the voltage limited to about 1 kV. In the relays described under 5.2.8.1 and 5.2.8.2 separate voltage limiting resistors will be necessary. In the relays described under 5.2.8.3 the resistors in series with high set unit act as voltage limiting resistors also.

5.2.8.5 *Current transformer requirements, for high/medium impedance relays:*

a) All the current transformers should have the same ratio. Auxiliary current transformers for ratio correction should be avoided as a rule as these introduce dissimilarity and make calculation of settings difficult.

b) All the current transformers should be of the toroidal or low reactance type as the formula for voltage across the relay takes into account only the resistance of the current transformer secondary. Current transformer windings with tapped secondaries are also to be avoided unless the tapped portions are also uniformly distributed over the core.

c) Auxiliary current transformer secondary rating of 1 A is to be preferred as it reduces the voltage across the relay under through fault conditions, and allows lower voltage settings to be adopted. This reduces current transformer magnetising currents at pick Up voltage, thereby increasing scheme sensitivity.

d) A high current transformer ratio of the order of 800/1 or 1 000/1 should be adopted without regard to the individual circuit rating. However, due consideration should be given to the maximum bus

coupler transfer load as well as the effective primary operating current setting while choosing the ratio. The current transformer ratio should also be as high as possible irrespective of individual circuit ratings. This reduces the secondary current for the maximum through fault levels resulting in lower relay voltage setting. The effect on the minimum primary operating current has, however, got to be watched. Due consideration should also be given to maximum bus coupler transfer load in selecting current transformer ratio.

e) The current transformer secondary resistances should be kept as low as possible.

f) The knee point voltage of the current transformers (defined as the voltage on the current transformer magnetisation characteristics at which a 10 percent increase in voltage results in a 50 percent increase in magnetising current) should not be less than twice the voltage calculated across the relay under maximum through or external fault conditions. This is expressed by the following formula:

$$V_k = \frac{2\ (R_s + Z_r)\ I_f}{N}$$

where

V_k = current transformer knee point voltage,
I_f = maximum short circuit current rating of the switchgear,
N = current transformer ratio,
R_s = current transformer secondary resistance, and
Z_r = maximum lead burden between the relay and the current transformer.

The value of V_k is usually calculated taking the current transformer farthest from the relay taking into account maximum r and I_f is taken as the current corresponding to the actual maximum fault current.

g) The magnetising currents drawn by the current transformer at the relay setting voltage should be low enough to ensure that the primary operating current is not more than 30 to 50 percent of the minimum fault current:

thus,

$$I_e < \left\{ \frac{(0{\cdot}3 \text{ to } 0{\cdot}5)\ I_f\,(\text{min})}{N} - i_r \right\} \times n$$

where

I_e = magnetising current drawn by the current transformer;
$I_f\,(\text{min})$ = minimum fault current;
n = number of current transformers that are paralleled;

N = nominal current transformer ratio; and

i_r = relay branch current at setting, including the current drawn by voltage limiters, supervisory relays, etc.

5.2.9 *Typical High/Medium Impedance Schemes* — The basic types of schemes are:

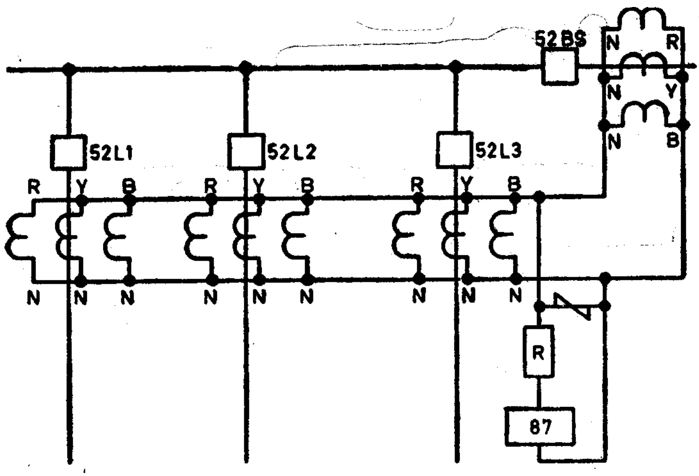
a) schemes for earth fault protection only using a single pole relay,

b) schèmes for phase' and earth fault protection using a single pole relay, and

c) schemes for phase and earth fault protection using a 3-pole relay.

5.2.9.1 Schemes *for earth fault protection only using a single pole relay* — A typical scheme is illustrated in Fig. 17. The three current transformers of each circuit are parallelled with those of all the other circuits and the relay connected across these current transformers. It will be seen that the relay responds only to zero sequence currents, that is, to earth faults only.

As most faults involve earth, there appears to be some justification in adopting such schemes, particularly for the comparatively less important installations. However, compared to a phase and earth fault scheme, economy is achieved only in respect of relays, as the current transformer requirement is the same. The saving, therefore, is not of much significance. Further, in systems where the earth fault currents are limited (for example resistance earthed systems) and with the large number of current transformers



52BS, 52L1, 52L2, 52L3 — Circuit Breakers
87 — Relay
N- Current Transformer Ratio

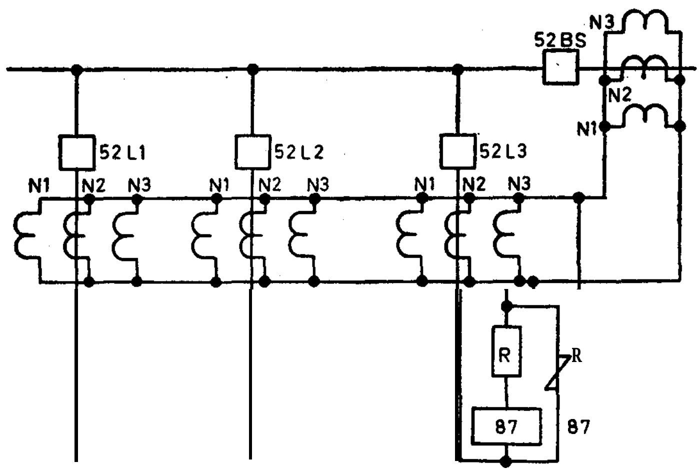
FIG. 17 EARTH-FAULT PROTECTION USING A SINGLE POLE RELAY (TYPICAL)

in parallel, the minimum primary operating current may not he **sufficiently** low.

5.2.9.2 ***Schemes for phase and earth fault protection using a single pole relay — There*** are two typical varients, namely :

a) One typical arrangement for resistance earthed. systems is shown in Fig. 18 and it will be seen that the basic connection is similar to that of Fig. 17. However, the ratio of the current transformers in the ***R*** phase of all the circuits is ***N1***, in the ***Y*** phase ***N2*** and in the ***B*** phase ***N3*** with the result that there is a current in the relay for all types of internal faults. The magnitudes of the current in the relay for the different types of the faults depends upon the actual current transformer ratios ***N1***, ***N2*** and ***N3***. With a proper choice of these ratios, the earth fault sensitivity can be made high compared to phase fault, the scheme being then suitable for systems where earth fault currents are limited.

   Phase fault protection is also provided by this scheme. Advantages over a scheme using three relays are that only two bus wires between current transformers and the relay are required. Also the number of auxiliary switches on the isolators in a double bus substation is considerably reduced. The current in the relay branch for assumed current transformer ratios of **300/1, 400/1** and **500/1** in the ***R***, ***Y*** and ***B*** phases respectively for the various types of fault work out as given in Table 1.



52BS, 52L1, 52L2, 52L3 — **Circuit Breaker**
87 — Relay
N1, N2, N3 — **Current Transformer Ratios in R, *Y*, and *B* Phases respectively**

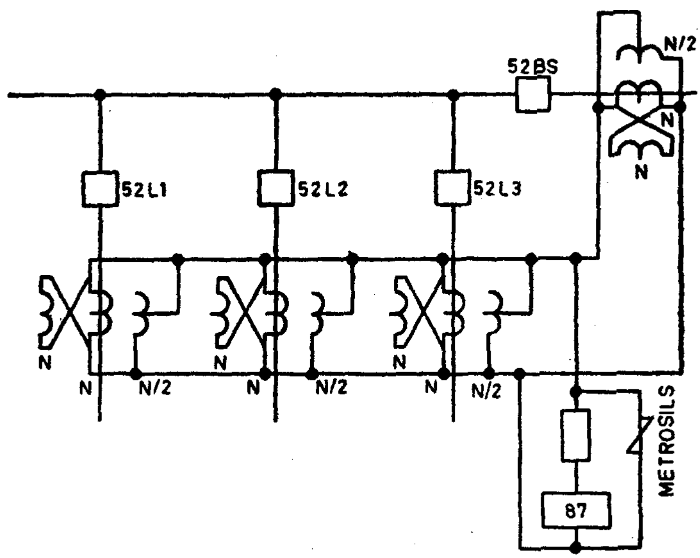
FIG. 18 PHASE AND EARTH FAULT PROTECTION USING A SINGLE POLE RELAY (FOR RESISTANCE EARTHED SYSTEMS) (TYPICAL)

TABLE 1 COMPARISON OF RELAY CURRENTS FOR DIFFERENT FAULTS

[*Clause* 5.2.9.2(a)]

TYPE OF FAULT	RELAY CURRENT AS A PERCENTAGE OF THAT ON A *R-E* FAULT
R-E	100
Y-E	75
B-E	60
R-Y	25
Y-B	15
B-R	40
R-Z--B	35

b) In the other current transformers of two phases having the same ratio are cross-connected and paralleled to the current transformer of the third phase which has half the ratio of the other current transformers as shown in Fig. 19. The Table 2 gives the comparison of relay currents for different type of faults.



52BS, 52L1, 52L2, 52L3 — Circuit Breakers
87 — Relay
N — Current Transformer Ratio

FIG. 19 PHASE AND EARTH FAULT PROTECTION USING A SINGLE POLE RELAY (FOR SOLIDLY EARTHED SYSTEMS) (TYPICAL)

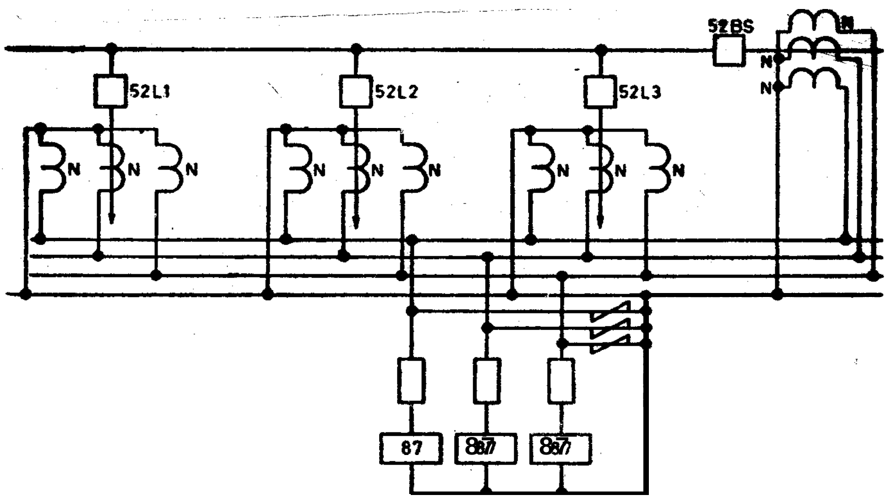
TABLE 2 *COMPARISON OF* **RELAY CURRENTS** *FOR* **DIFFERENT TYPES** *OF* **FAULTS**

[*Clause* 5.2.9.2(b)]

TYPE OF FAULT	RELAY CURRENT AS PERCENTAGE OF THAT ON A *R-E* FAULT
R-E	100
Y-E	100
B-E	200
R-Y	200
Y-B	100
B-R	300
R-Y—B	260

It will be seen from Table 2 that the sensitivity for phase faults is generally better than for earth faults and hence it is more suitable for solidly earthed systems.

The advantages mentioned for the scheme under 5.2.9.2 (a) hold good for this scheme also.



52BS, 52L1, 52L2, 52L3 — Circuit Breakers
87 — Relay
N — Current Transformer Ratio

FIG. 20 PHASE AND EARTH FAULT PROTECTION USING A THREE-POLE RELAY (TYPICAL)

5.2.9.3 *Scheme for phase and earth fault protection using a 3-pole relay (for both solidly earthed and resistance earthed systems)* — A typical scheme is shown in Fig. 20. The current transformers of each phase are paralleled separately using four bus wires. Three relays, one per phase? are required, and connected between phase and neutral. The sensitivity for phase and earth faults is the same. The number of current transformers in parallel is less than that in the other schemes, thereby reducing the minimum primary operating current. This scheme is very widely used on the more important sub-stations especially at the higher voltages.

5.2.10 *Biased Differential Relays* — The technique of biasing is extensively used to increase the stability ratio of differential schemes such as transformer protection, pilot wire protection, etc, and is advantageously used for bus protection also. Biasing makes it possible to use reduced stabilizing resistor values in circulating current high impedance schemes which in turn relax the requirements of the current transformers but the schemes tend to be more complicated.

The biased schemes as applied to bus bar protection fall in two major categories:

a) with resistance stabilising, and

b) without resistance stabilising.

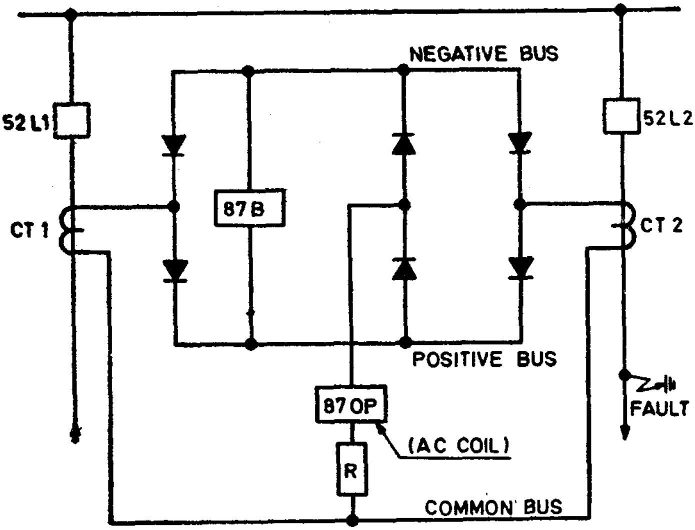
5.2.10.1 *Biased schemes using resistance stabilising* — The principle of biased scheme is shown in Fig. 21A. The relay has a single bias winding 87 *B* which is fed with the algebraic sum of rectified currents corresponding to the individual circuit currents.

The operating coil is shunt connected, with a series connected stabilizing resistor. The operating coil itself can be ac or dc operated and will have to be fed through a rectifier bridge if it is the latter as shown in Fig. 21 B. Under normal conditions of load only the bias coil remains energised. When a through fault occurs causing saturation in the current transformers, the spill currents so set up flow through the operating coil. However, the secondary equivalent of the through current flowing through the bias winding, restrains the relay against operation.

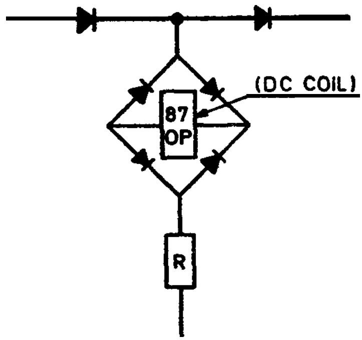
The stabilizing resistors ensure that the overall relay branch impedance is not low enough to shunt a major portion of the fault current. Its value is chosen such that only that much of current flows through the operating coil which can be safely handled by the bias coil.

If B = bias ratio, and
I_s = the secondary equivalent of through fault current,

Then permissible spill current = $B.I_s$.



21A Principle



21 B Alternative Connection for Relay Operating Coil

87B — Relay Bias Winding
87OP — Relay Operating Winding
R — Stabilizing Resistor
52L1, 52L2 -- Circuit Breakers
CT1, CT2 — Current Transformers

FIG. 21 BIASED SCHEMES USING RESISTANCE STABILIZING

If only one of the current transformers saturates completely and other current transformers have no saturation, the impedance of the loop across the relay is (R_S+2r)

where

R_S = the current transformer secondary resistance, and
r = lead impedance between the saturated current transformer and the relay (one way).

The relay current under this condition $= \dfrac{I_S \times (R_S+2r)}{Z+(R_S+2r)}$

where $Z=$ relay branch impedance

For non-operation of de protection, therefore,

$$\frac{I_S\ (R_S+2r)}{Z+\ (R_S+2r)} < B.\ I_S.$$

or

a) $Z > \dfrac{R_S+2r}{B}$, if (R_S+2r) is very small compared with Z.

b) $Z > \dfrac{R_S+2r}{B} - (R_S+2r)$, if Z and (R_S+2r) are of the same order of magnitude.

Usually the value of Z obtained from (a) also satisfy equation (b) above.

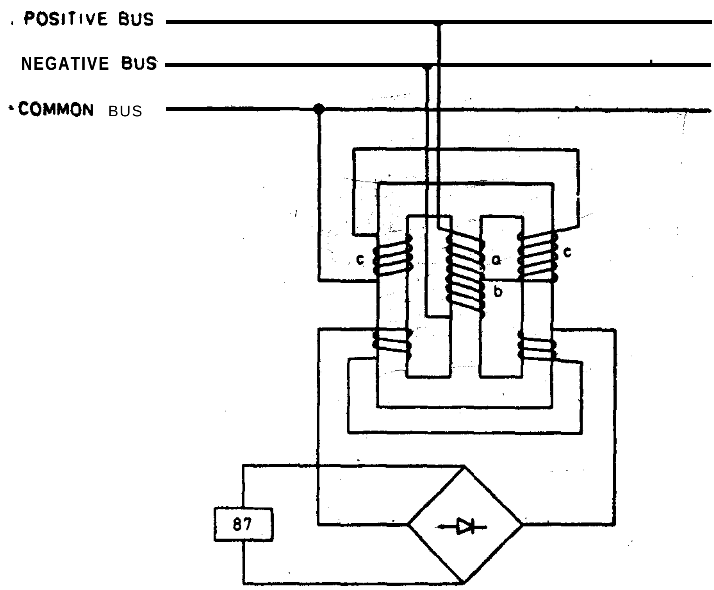
53.10.2 *Biased schemes without resistance stabilizing* — The connections *are* identical to that for the scheme described in 5.2.10.1, the difference being in the relay itself. A typical relay consists of a *sensitive* telephone type movement fed by a transductor *via* a bridge rectifier. The transductor has a high permeability three-limb core. The bias winding is uniformly distributed over the middle limb. It is tapped in the centre and connected to the operating winding which is distributed equally over the two outer limbs. The short circuited winding on the middle limb provides a smoothing effect for the dc bias flux. The output winding is on the two outer limbs as in Fig. 22A. Under through fault conditions, the bias current in both the half-cycles nearly saturates the core and even with spill currents in the operating winding, no output current is produced. Under internal fault conditions, the bras effect is very much reduced, and the current in the operating winding is very much higher, thereby resulting in an output current.

This can be readily understood by referring to the Fig. 223. The dc bias flux in the centre limb determines the point of operation of the transductor on the *BH curve.* On through faults the current is available during both half-cycles in either half of the bias winding (that is *a* and *b*). Also the

magnetic core is nearly saturated with the bias flux and so no output is available to operate the telephone relay. Even if any spill current exists in the operating winding it is not capable of producing enough output to cause the relay operation.

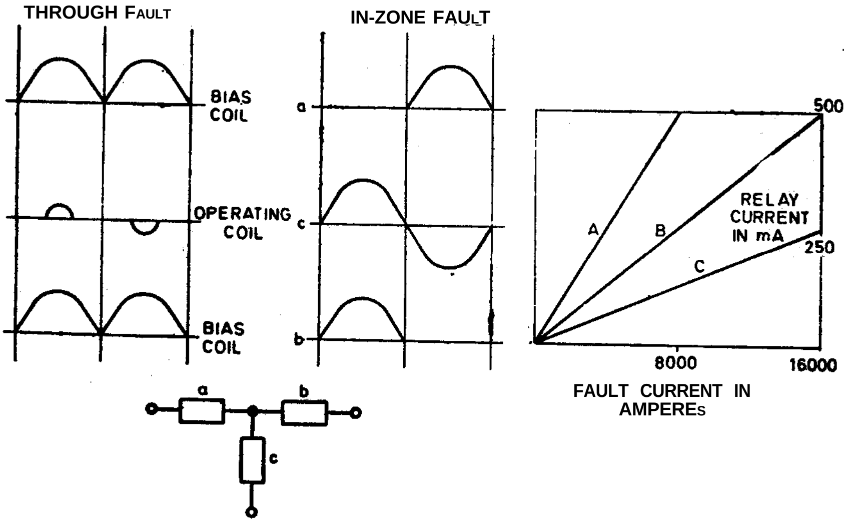
During external faults the dc bias effect is reduced considerably since the bias currents in the windings a and *b* flow during alternative half cycles. On the other hand the operating winding carries currents during both the half cycles. Consequently the output winding develops enough output to operate the relay.

5.2.10.3 In the practical application of the schemes, summation current transformers (one per set of main current transformers) are normally used. These summation current transformers have a tapped primary to which the three phases of the main current transformers are connected, the sewndary of the summation current transformers providing a single phase



22A Transductor Relay

FIG. 22 BIASED SCHEME WITHOUT RESISTANCE STABILIZED (TYPICAL) — *Contd*



22B Relay Currents During Faults

A — Current available for internal fault
B — Current for operation (through faults)
C — Current for operation (internal fault)

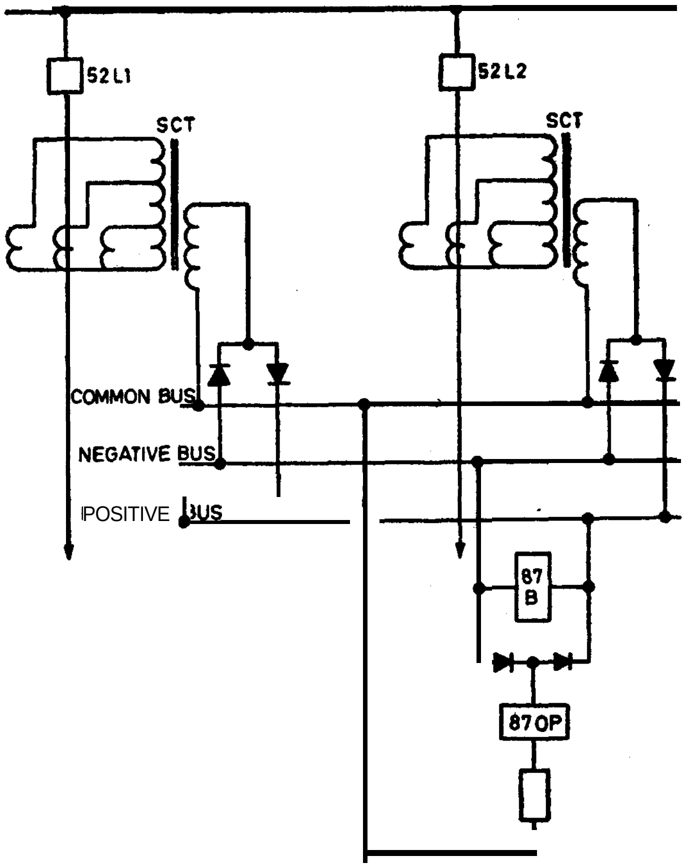
FIG. 22 BIASED SCHEME WITHOUT RESISTANCE STABILIZING (TYPICAL)

output. The connection for one set of main current transformers is shown in Fig. 23. The advantage of using summation current transformers are:

- **a)** a single relay is used for all three phases;
- **b)** a definite bias current is available for all types of external faults;
- **c)** lead burden on main current transformers is less, provided these current transformers are located judiciously;
- **d)** secondary cabling is reduced; and
- **e)** auxiliary switch requirement in double bus bar arrangement is reduced.

The main drawbacks are:

- a) the setting for various tapes of faults is different, needing careful analysis; and
- b) bias effect is less for phase faults than for earth faults.



52L I, *52L2* — Circuit Breakers
SCI — Summation Current Transformer
87B — Relay Bias Coil
870P — Relay Operating Coil

FIG. 23 USE OF SUMMATION CURRENT TRANSFORMERS IN BIASED SCHEMES (TYPICAL)

6. APPLICATION OF BUS BAR PROTECTION TO OUTDOOR INSTALLATION

6.1 Common Bus Bar Arrangements and Current Transformer Locationa

6.1.1 Five common layouts have been illustrated in Fig. 24A to 24E. The simplest of all, the single bus bar arrangement Fig. 24A does not pose any

difficult problem at all from the protection application point of view as no complicated current transformer switching is involved. The other forms of layout, Fig. 24B to 24D do sometimes involve a certain amount of current transformer switching which however, depends to a great extent, upon the location of the current transformers themselves. The different possible locations of the current transformers for the various circuits have been marked (X for bus couplers, *Y* and *YY* for feeders and *Z* for bus section circuits). The degree of coverage afforded by the protection under any given mode of primary circuit switching, is also largely decided by the current transformer location. The ideal layout from the application viewpoints, therefore, would be that which needs minimum or no current transformer switching, but which affords maximum coverage by the protection under all contemplate modes of switching. The mesh layout in Fig. 24E also, presents no difficulty as far as application is concerned. In fact, it does not at all require a separate form of bus protection since the circuit protection itself adequately covers the bus bars against faults.

6.2 The Practical Scheme of Bus Protection for Outdoor Installation — The practical scheme for an outdoor installation essentially has the following features usually incorporated:

a) Zonal discrimination,

b) Check feature,

c) Secondary wiring supervision,

d) dc circuit for selective tripping, and

e) Alarm indication (annunciation).

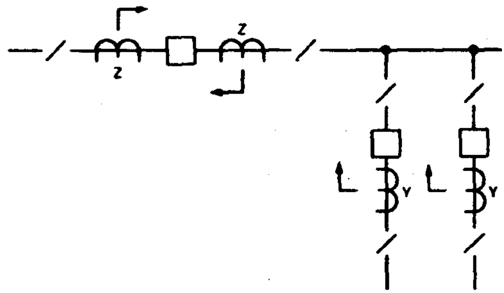
6.2.1 *Zonal Discrimination*

6.2.1.1 With a view to limiting the extent of outage of circuits to the barest minimum in the event of a bus fault it is the normal practice to duplicate and/or sectionalise the bus bars, with the circuits distributed over the various sections. However, the full advantage of such precautions can be realised only if the bus protection can discriminate the faulty section from others and isolate the same selectively.

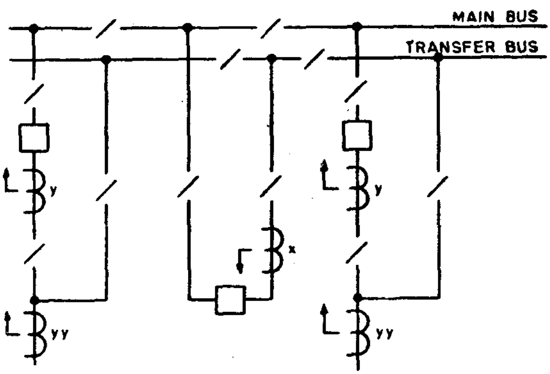
6.2.1.2 A practical scheme of protection is therefore to be designed to cover the entire bus bars in two or more zones as required, each zone being complete by itself, with the necessary protective and tripping relays.

How the zones are created for a typical duplicate bus bar execution is given in Fig. 25A. The secondaries of the current transformers of all the circuits connected to a particular bus bar/section are paralleled selectively and connected to the associated differential relay. Since the bus coupler and bus section switches are common to the zone on either side, current transformers are also required on either side for these circuits in an ideal case.

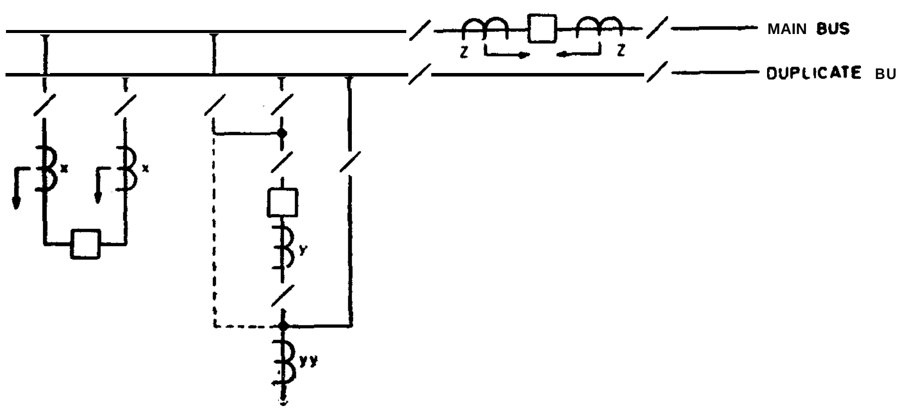
The duplicate bus bars as given in Fig. 25A are sectionlized by isolators.



24A Single Bus Bar

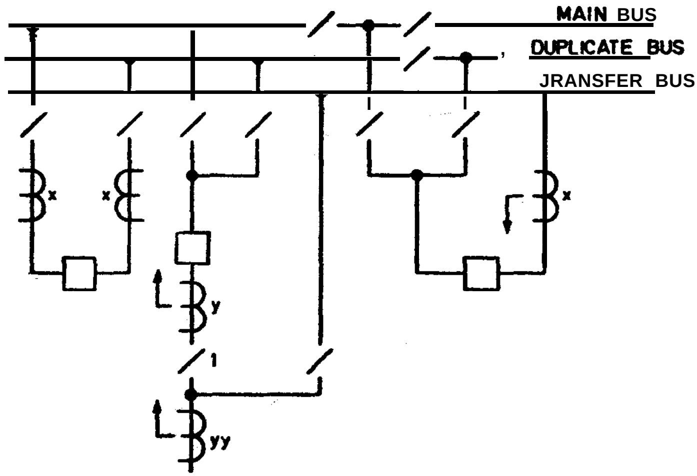


24B Transfer Bus

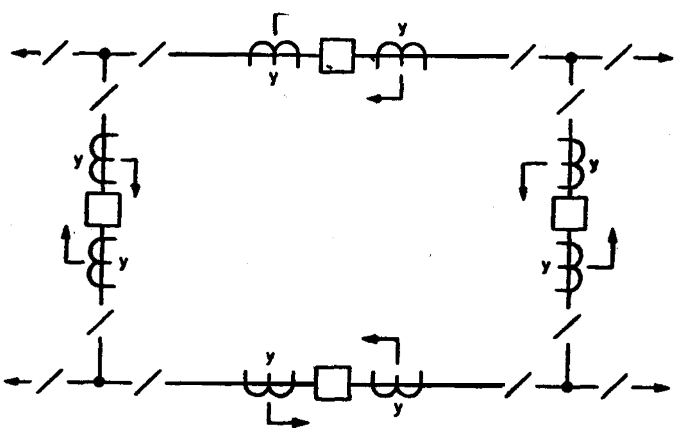


24C Duplicate Bus

FIG. 24 BUS BAR LAYOUTS SHOWING PROTECTION CURRENT TRANSFORMER LOCATIONS (TYPICAL)—*Contd*



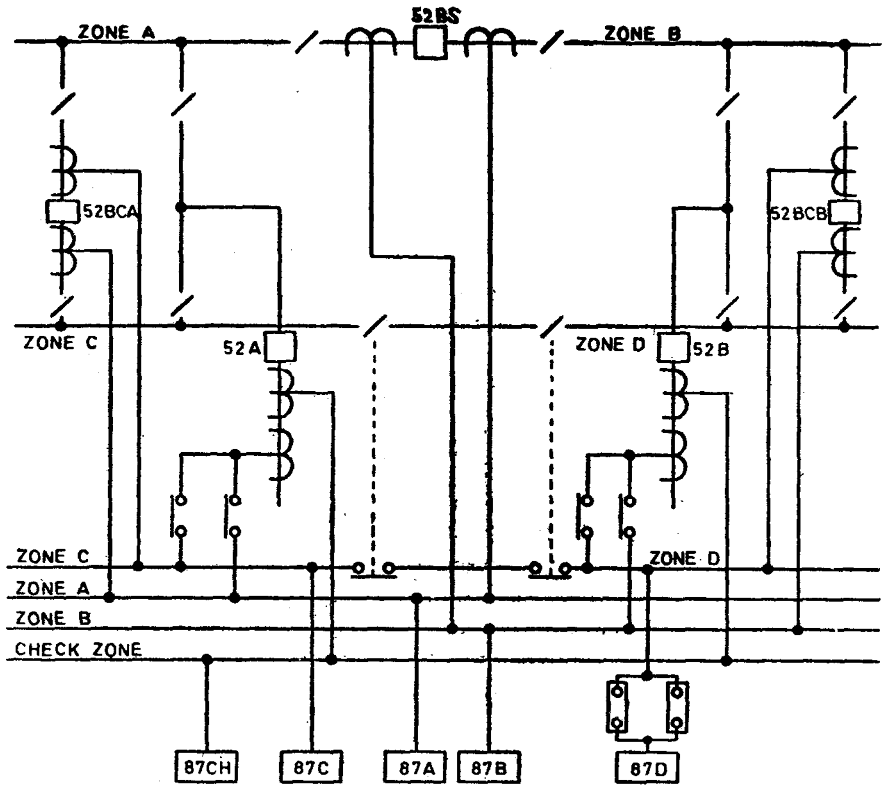
24D Duplicate Transfer Bus



24E Mesh Bus

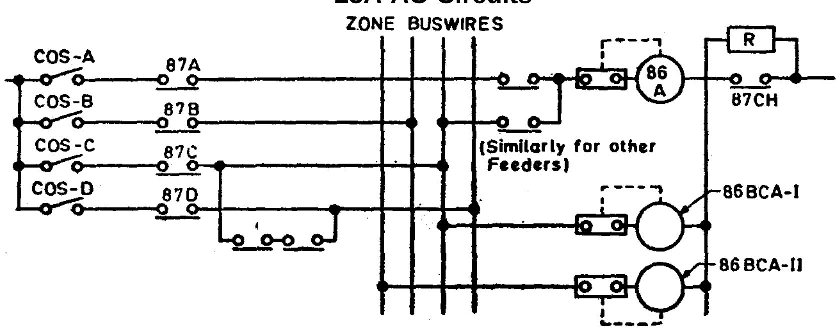
FIG. 24 BUS BAR LAYOUTS SHOWING PROTECTION CURRENT TRANSFORMER LOCATIONS (TYPICAL)

The isolators being non-automatic devices which cannot trip to isolate the faults as breakers do, current transformers are not required to be provided on either side of them. Thus, when the isolators are kept closed the entire



52BS, 52BCA, 52BCB, 52A, 52B — Circuit Breakers *87* — Relay

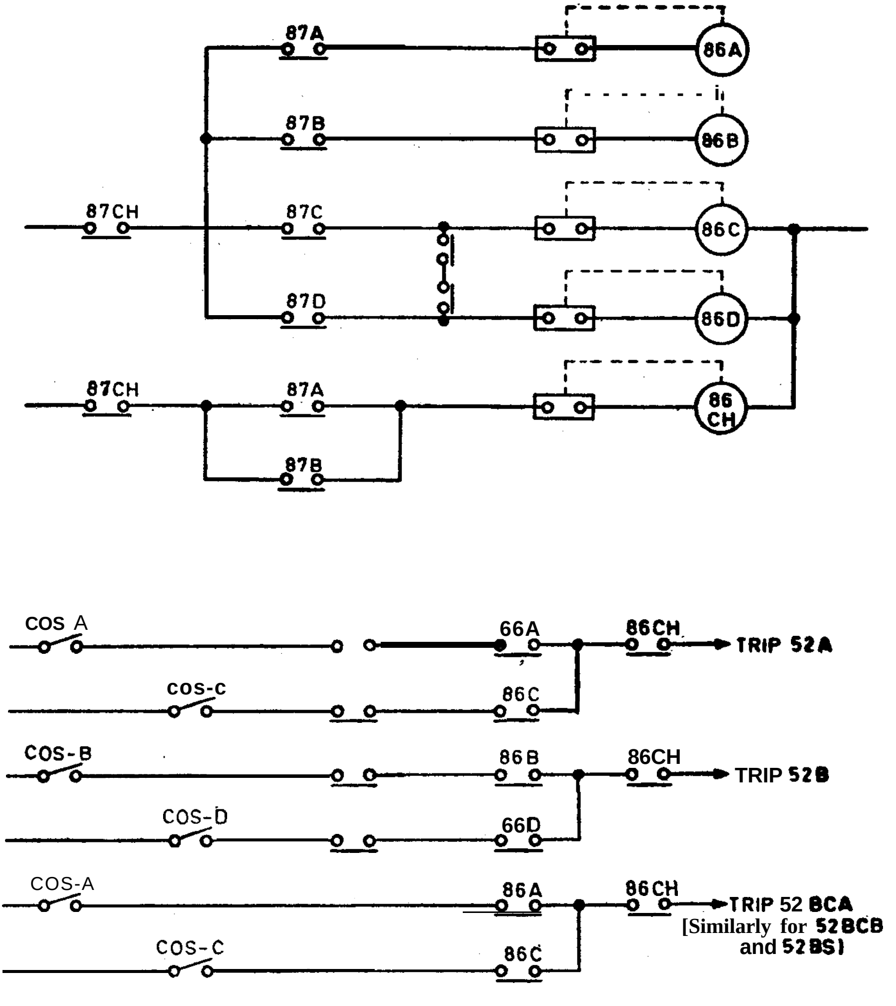
25A AC Circuits



COS — Cut Off Switch *86* — Trip Relays 87 — Relays

25B Type I Trip Circuits

Fig. 25 Zones in Bus Bar Protection (Typical)—*Contd*



COS — Cut-Off Switch
86 — Trip Relays
87 — Relay
52 — Circuit Breaker

25C Type II Trip Circuits

FIG. 25 ZONES IN BUS BAR PROTECTION (TYPICAL)

duplicate bus bar can be considered as a single zone. On the other hand when the isolator/isolators is/are opened, the two sections of the duplicate bus bars which are electrically separate, now, should be considered as two separate zones. Consequently, the current transformers groups of two zones (C and *D*, in this instance) are connected together or disconnected through the normally open auxiliary switches of the isolator. It will however be noted that when the differential relay is of medium or low impedance type such paralleling of relays of two zones can increase the primary operating current of the protection. It is therefore, essential in those cases to disconnect one of the two relays and tie together the corresponding dc trip circuits. This is also achieved through the use of auxiliary contacts of isolators (see Fig. 25B and 25C).

Further, the feeders, in a duplicate bus layout, are capable of being connected to either of the bus bar and fault to earth existing between the local isolator *89LA* and the current transformer, the feeder is energised from the remote end inadvertently (*see* Fig. 26A).

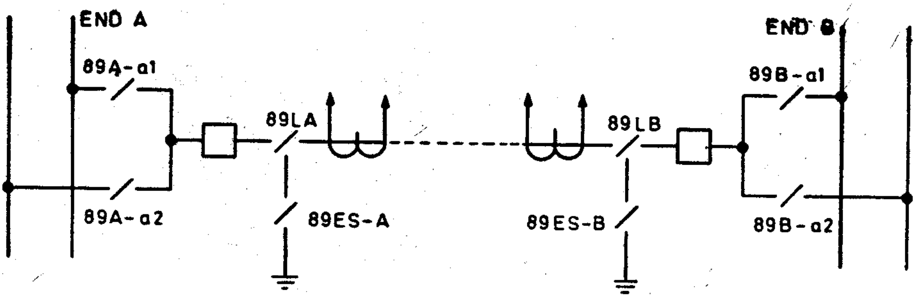
When an earth fault occurs in a solidly earthed system, some of the fault currents can flow through the conductors of the feeder, if it is isolated, from both ends *A* and *B* earthed at these ends through earth switches. These currents also can damage the current transformers if they are left open-circuited.

Of course, the above is true only if the current transformers are located towards the line side of the feeder isolator/earth switches. Thus the chances of the above happening are less in the case of oil circuit-breakers with bushing current transformers than for air blast breakers with separate outdoor current transformers.

Automatic shorting of current transformers through auxiliary switches as shown in Fig. 26B and 26C can sometimes lead to further complications with layouts shown in Fig. 24C, for example, the mere fact that both isolators *a1* and *a2* are open does not necessarily mean that the circuit is disconnected from the bus bars. In such cases, therefore, manual unshorting and reconnection of the current transformer secondaries as required, will be most ideal.

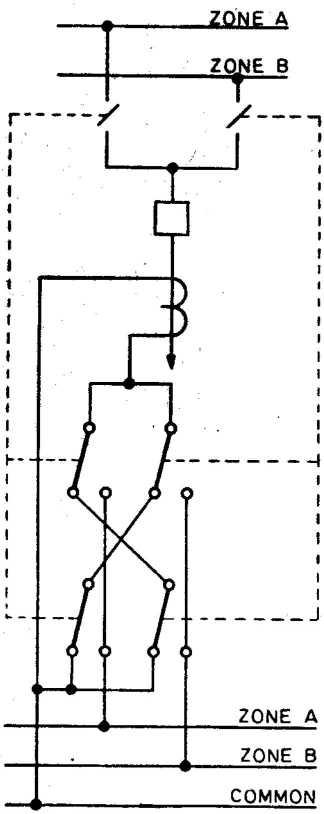
6.2.1.3 *Repeater relays for current transformer secondary switching* — In cases, where a scarcity of isolator contacts exists, it may become necessary to use contact multiplying relays. Depending upon the type of isolator, that is, manually-operated or motor/pneumatic-operated, these relays can be of two types.

6.2.1.4 *Relays for manually-operated isolator* — A typical method of using relays for contact multiplication in the case of manually-operated isolators is indicated in Fig. 27. It will be noticed that normally closed contacts of the isolator are used to energize the relays. This is considered a better arrangement compared to using normally open contacts of the isolator as it results in a 'fail-safe' scheme. This will he evident from Fig. 27 because it can be

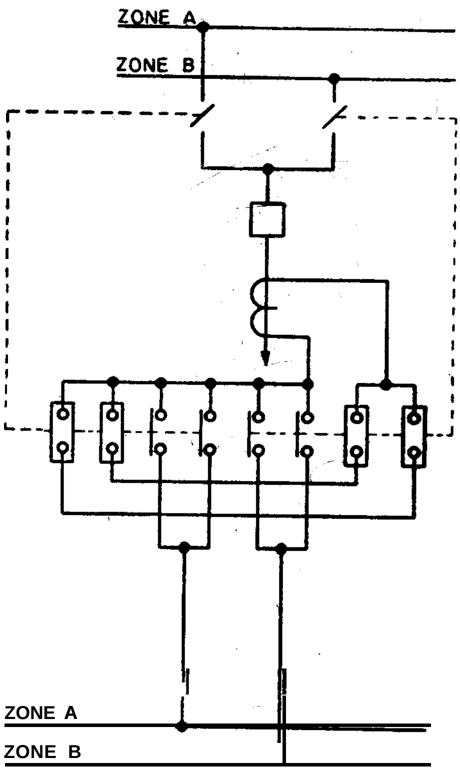


89— Isolator

26A Earth Fault



26B Change-Over Type Auxiliary Switches



26C Break-Make Auxiliary Switches

FIG. 26 USE OF ISOLATOR AUXILIARY SWITCHES FOR CURRENT TRANSFORMER SWITCHING (TYPICAL)

seen that, in the event of a failure of dc supply to the relays, no current transformer gets open-circuited as would be the case otherwise.

Since this arrangement requires the relays to be kept continuously energised, the relays should be continuously rated for this application. Also the normally closed auxiliary switch should open earlier than the closing of main contacts and close later than the opening of the main contacts. Duplication of the auxiliary contacts of the isolator also is recommended though the same for the relay contacts may not be really necessary since usually the relay contacts are more reliable than the auxiliary switches of isolators.

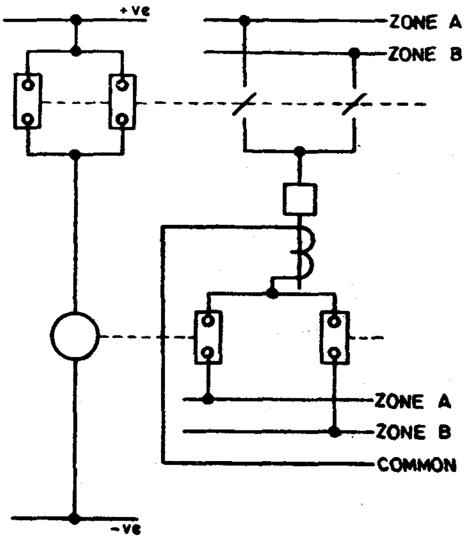


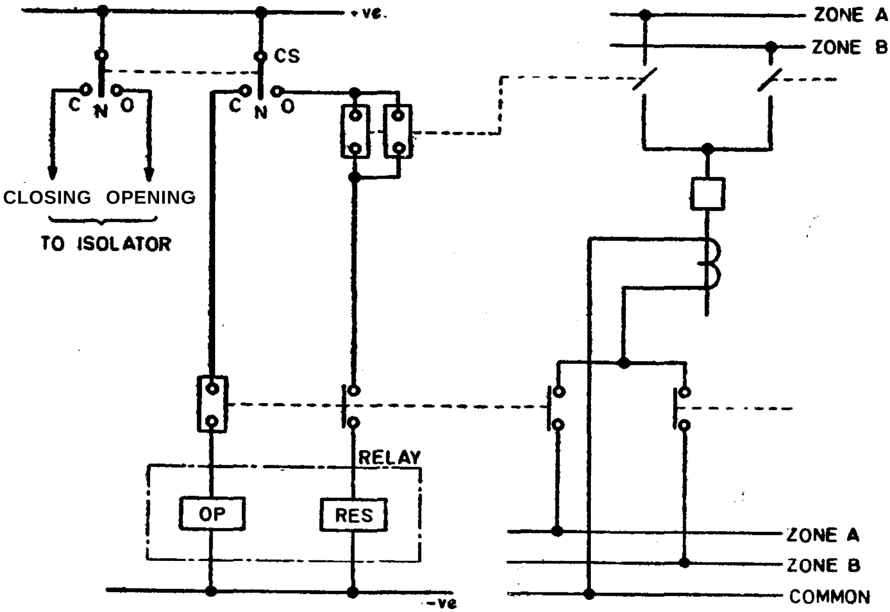
FIG. 27 RELAY FOR CURRENT TRANSFORMER SWITCHING (MANUAL ISOLATORS) (TYPICAL)

6.2.1.5 ***Relays for motor-operated isolators*** *-A* typical method -of using relays for motor-operated isolators is given in Fig. 28. The relay should be an electrically reset type having separate 'operating' coil *OP* and 'resetting' coils RES. When the 'operating' coil is energised the contacts close and latch in, when the 'reset' coil is energised the latching is removed and the contacts open out. An additional pole of the control switch CS of the isolator energises the relay at the same time as the closing command is given to the isolator. The relay picks up and its contacts make the secondary current circuits, therefore, much earlier than the isolator main contacts make. Similarly when the opening command is given, the reset coil of the relay does not get energised till the isolator has acutally opened.

Further, the contacts of the relay being 'latch-in' type, there is no fear of

the contacts open-circuiting the CT secondary in the event of a dc failure. Also the relay coils are not kept continuously energised.

Normally closed contacts of the isolators are required for the relay operation and should be duplicated for added reliability.



CS — Control Switch
OP — Operating Coil
RES — Resetting Coil

FIG. 28 RELAY FOR CURRENT TRANSFORMER SWITCHING (REMOTE CONTROLLED ISOLATORS) (TYPICAL)

6.2.1.6 There is one disadvantage in using relays for switching current transformer secondaries. It would involve in drawing the individual current transformer leads to the control room where the relays are located before paralleling and connecting to the differential relay. Thus, the secondary lead resistance and consequently the knee-point voltage requirements of the current transformers will be increased. One way to avoid this would be to locate the switching relays in the switchyard itself inside local control rooms. This would also reduce the amount of cabling between control room and switchyard.

6.2.1.7 *Location of current transformers* — Various methods of locating current transformers for bus bar protection on the feeder circuits, bus section circuits and bus coupler circuits had been shown in Fig. 24. For feeder

circuits two alternative locations namely *Y* and *YY* have been shown. What is to be observed from Fig. 24 is that all the bus bar protection current transformers have been so positioned with reference to the associated circuit-breaker that the latter is fully covered by the zone of protection each current transformer defines. This is very essential to isolate effectively fults anywhere on the bus bar sections covered by these zones, leaving no blind spots.

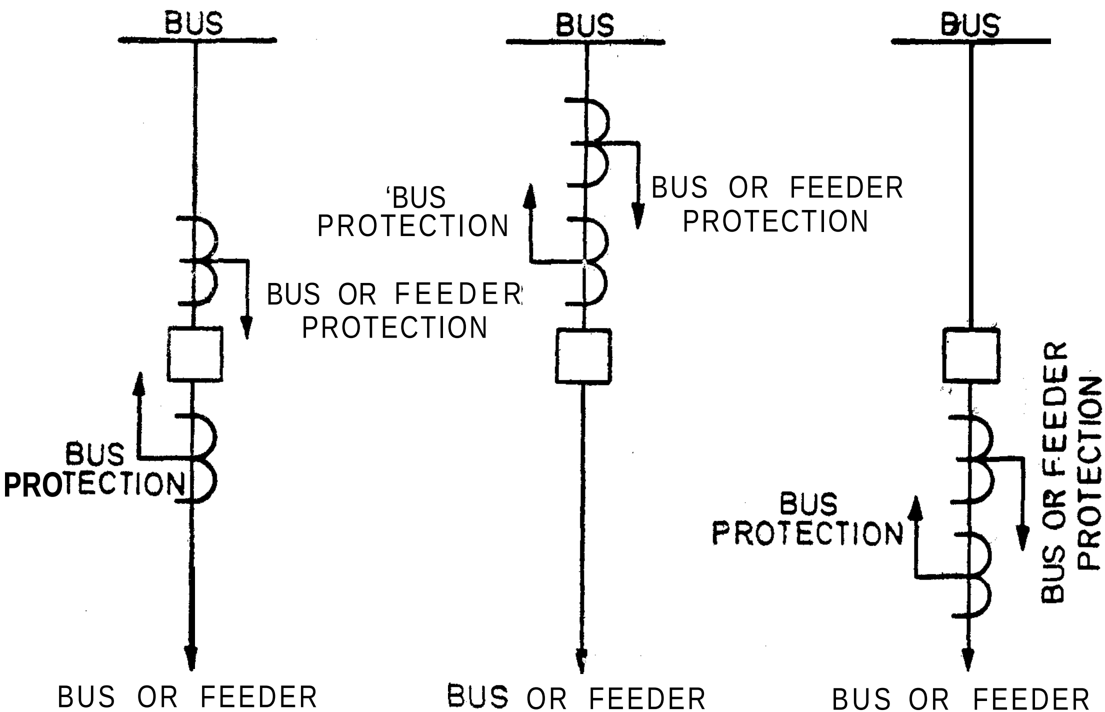
However, it will not always be possible to locate the current transformers as shown in Fig. 24 due to economical reasons. This is especially true with outdoor current transformers. In such cases alternative locations as shown in Fig. 29 have to be accepted. These alternative locations, however, would fall short of the ideal in the matter of full zonal discrimination, as can naturally be expected. It will thus be clear from Fig. 30A that faults in locations such as *F* continue to be fed even after the associated protection operates to trip the circuit-breaker. In the case of feeders equipped with 3-step distance protection, such faults arc not left for long but would eventually be cleared by the remote end protection operating in zone *B* time. However, such delayed clearance (say 0·25 second) is not acceptable in many *cases* and effective measures against fults in such blind spots have to be taken. They usually take the form of an intertripping relay.

69.1.8 *Intertripping between zones* — Typical cases of intertripping between adjacent zones of protection-have been shown in Fig. 30. Referring to the arrangement shown in Fii. 30A it will be seen that a fault at *F* causes zone *A* protection to operate and trip all circuits connected to zone A, including the bus *section breaker 52BS.* However, the fault is continued to be fed from zone *B* without being detected by zone *B* protection because it is outside zone *B.* However, the fact that wne *A* has operated and still the fault continues to be fed are indications that the fault is in the 'blind spot'. This is detected by the interlocked overcurrent relay 511 which is energised by a third set of current transformers and is triggered for operation by wne A protection as indicated. Relay *51I,* when operated will bypass the wne *B* differential relay contacts to trip all circuits connected to wne *B.*

In Fig. 30B the operation of an interlocked overcurrent relay for feeder circuit is shown. The particular location of current transformers shown has been chosen only to illustrate the trip circuit selection for intertripping.

Alternatively a timer can be used in place of the interlocked overcurrent relay as shown in Fig. 30C which is self explanatory. In order to be f&m-&rally the same as an interlocked overcurrent relay, the timer should be such that it requires a continuous signal till the expiry of the set to give a trip impulse. To the same end, the contacts that energise the timer should be self-reset, preferably that of the differential relay itself. The setting adopted on the timer, should give allowance for the time of operation of zone A protection plus the opening time of the breakers.

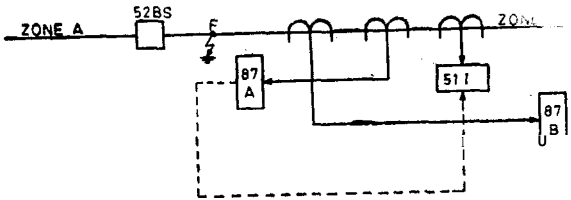
This method of intertripping would be found very advantageous on generator circuits where the bus protection is required to inter-trip the generator



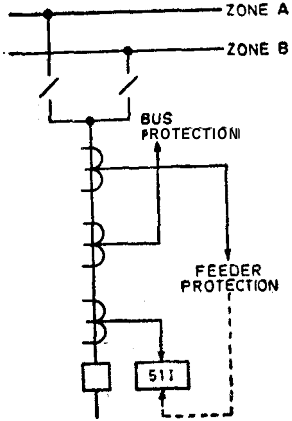
29A Ideal | **29B** Preferred Arrangement* | 29C Preferred Arrangement?

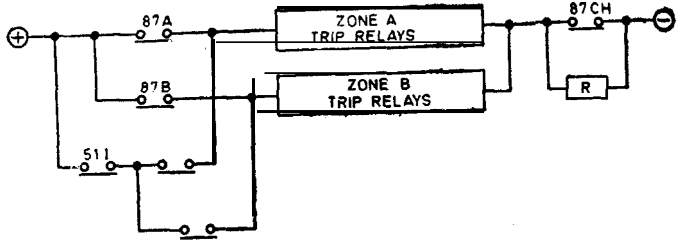
***Outdoor Current Transformers when infeed from feeder side is larger.**
†Outdoor Current Transformers when infeed from bus side is larger.

FIG. 29 CURRENT TRANSFORMER LOCATION (TYPICAL)



30A Bus Coupler or Bus Section



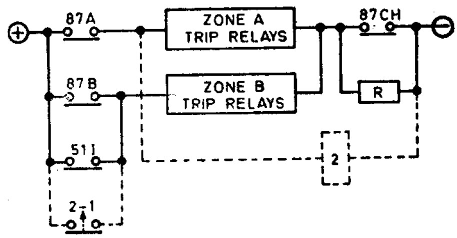


30B Feeder Circuits

2 — Timer
87A — Zone A Differential Relay
87B — Zone B Differential Relay
87CH — Check Differential Relay
51I — Interlocked Overcurrent Relay
52BS — Bus Section Breaker
R — Resistor

NOTE — Dotted line indicate circuitry when a timer is employed instead of *51I.*

FIG. 30 INTERTRIPPING BETWEEN ZONES (TYPICAL) — *Contd*



2 — Timer
87A — Zone A Differential Relay
87B — Zone B Differential Relay
87CH — Check Differential Relay
51I — Interlocked Overcurrent Relay
R — Resistor

30 C **Use of Timer**

NOTE - Dotted line indicate circuitry when a timer is employed instead of *51I*.

FIG. 30 INTERTRIPPING BETWEEN ZONES (TYPICAL)

circuits. In such cases due to the generator decrement the conventional interlocked overcurrent relay may not operate for certain faults.

When the bus protection is required to intertrip the feeder protection, the method of such inter-tripping would depend to a large extent upon the length of the feeders and the type of protection provided for than.

Thus,

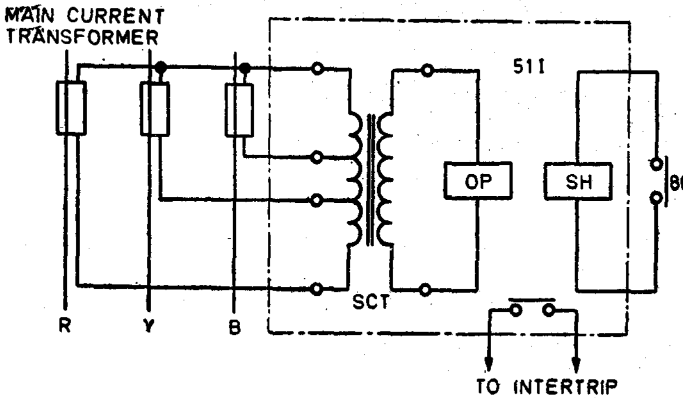
a) for short feeders, direct wire dc intertripping can be attempted.

b) for longer feeder-s having distance protection with carrier inter-tripping or blocking arrangement the interlocked ovacurrent relay can be used for sending the intertrip signal or de-blocking the protection.

c) with unit type pilot wire protection, the interlocked overcurrent relay can be made to open or short the pilot wires depending upon whether the protection is current or voltage balanced to cause inter-tripping of the remote circuit breaker, provided the fault infeed is sufficient to operate the remote end protection.

6.2.1.9 *Interlocked overcurrent relays* — These are conventional relays, specially designed for this application, available with the various relay manufacturers. Alternatively an ordinary overcurrent IDMT relay with slight modification, can also be used.

6.2.1.10 *Conventional type interlocked overcurrent relays* — A relay of this type is diagramatically represented in Fig. 31. This is a single pole IDMT disc type unit having a built in summation current transformer to feed the operating coil of the relay. The relay has a wound shading coil instead of the short-circuited slug of the normal IDMT relays. This shading winding



51I — Overcurrent Relay
SCT — Summation Current Transformer
86 — Trip Relay (of bus protection) of the Circuit
OP — Operating Coil
SH — Shading Coil

FIG. 31 CONVENTIONAL INTERLOCKED OVERCURRENT RELAY

is not kept short-circuited, but brought out to separate terminals on the relay, and will be shorted only when the intertripping protection (for example, zone *A* in Fig. 30) operates.

The summation current transformer supplies the relay with a single phase operating current for all types of faults (for a typical summation current transformer design *see* Fig. 23). The value of the summation current transformer secondary currents for different types of faults of the same magnitude, however, are different for the reason that the effective stationary current transformer ratio changes with the type of faults. Thus with the connections shown in Fig. 31 the relay has a better sensitivity towards certain types of faults than to others. Typical settings for a particular make of relays are shown in Table 3.

TABLE 3 EFFECTIVE SETTINGS OF INTERLOCKED OVERCURRENT RELAYS
(*Clause* 6.2.1.10)

TYPE OF FAULT	EFFECTIVE SETTING (PERCENT OF RATED CURRENT)
R-E	35
Y-E	46
B-E	69
R-Y	138
Y-B	138
B-R	69
R-Y-B	80

At 5 times the setting current, the relay has an operating time of 0·4 second with time multiplier set at unity.

The variation of fault settings makes it very essential to check for positive relay operation for all types of faults. Especially, for generator circuits when relay operation depends upon generator infeed. The application needs careful study, because of the generator decrement mentioned under 6.2.1.8. The application of these relays for bus-coupler and bus section circuits does not usually pose any problem, though here too it is advisable to check for relay operation with the expected primary switching modes.

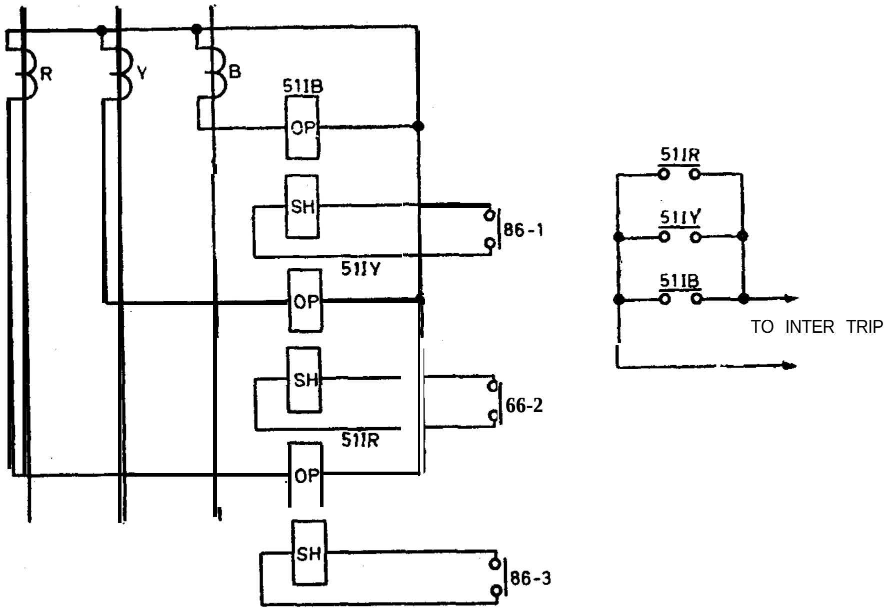
6.2.1.11 *Three pole IDMT relay as interlocked overcurrent relay*-A standard three pole IDMT relay with settings of say 20 to 30 percent of 1A or 5A can also be used as an interlocked overcurrent relay, provided these relays have wound shading coil separately brought out. The method of connection of the relays is given in Fig. 32. The relay connection, it will be noted, is exactly similar to that of any other 3 pole overcurrent relays. But setting, lower than full load can be adopted on these, the shading winding being kept open-circuited under normal conditions. However, the thermal withstand consideration sometimes preclude the use of the lowest setting in these relays.

6.2.1.12 Use *of single pole overcurrent relay as interlocked overcurrent relay* — This method is based on a connection of current transformers given in 5.2.9.2 (b) and is given in Fig. 33. It is better suited to the generator circuits where the effect of decrement is very much felt and where the current transformer ratios are more or less kept unaltered.

The peculiar connection of current transformers effectively replaces the summation current transformer. A conventional IDMT relay with 10 to 40 percent setting and 0 to 1·3 seconds definite minimum time-lag can be used. There is no necessity for a special relay with wound shading coil. The relay is normally kept short-circuited through normally closed contact of the bus bar protection trip relay so that it does not pick up on load. This JVC contact should have a high breaking capacity of about 50A.

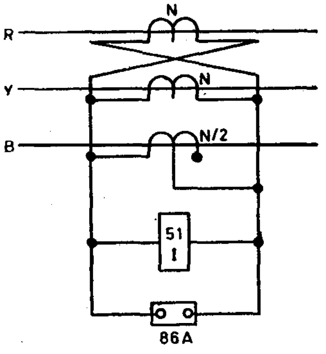
It is, however, recommended that the relay mentioned under 6.2.1.11 be used wherever possible as it has the least amount of complexity from application point of view.

6.2.2 *Check Feature* — Mal-operation of bus bar protection can result in wide spread system failure. It is therefore considered judicious to monitor its 'operation' by some form of check relay. It should not, however, be concluded that such a step is expedient due to some inherent flaws in the scheme itself. Specially when high impedance circulating current scheme is used the fact that the inherent factor of safety in the setting calculations is quite high and that any departure from the assumed conditions for calculation only results in an increase of the safety factor, rules out the possibility of mal-operation from the design point of view. The provision of a check feature is, therefore, purely a measure against mal-operation caused by



86 — Trip Relay
51 — Overcurrent Relay
OP — Operating Coil
SH — Shading Coil

FIG. 32 USE OF ORDINARY OVERCURRENT RELAY FOR INTERLOCKING USING 3 POLE EARTH FAULT RELAY (TYPICAL)



Fault	Relay Current as Percentage of that on a *R-E* Fault
R-E	100
Y-E	100
B-E	200
R-Y	200
Y-B	100
B-R	300
R-Y-B	260

N — Current Transformer Ratio
51I — Interlocked Overcurrent Relay
86A — Trip Relay

FIG. 33 SINGLE POLE IDMT RELAY USED AS INTERLOCKED OVERCURRENT RELAY (TYPCIAL)

external agencies. Incidently it also allows low settings to be adopted in some cases as discussed later.

6.2.2.1 The ideal check feature should possess the following characteristics :

a) The check feature should be provided by a relay which is physically different from the main relay.

b) It should pick-up for all types of faults that the main protection is capable of detecting.

c) The check feature should be at least as fast if not faster than the main protection for a given type of fault.

d) The source which feeds the check relay should be physically different from that which feeds the main protection.

e) The check feature should operate only for faults within the main zone/zones of protection and not for external faults.

6.2.2.2 *Check feature using separate sets of current transformers and relays* — **A separate** set of cores on the circuit protection current transformers is added with the ratios the same as for the main discriminating cores. The secondaries of all these current transformers are paralleled in groups, **one pre-**phase, and connected to a differential relay as in the case of the main protection. **However,** no attempt is made to switch these current transformer secondaries. The contact of the check relay is then wired in series with the main relay(s) contact for selective tripping (as shown in Fig. 30). Thus, so long as the fault lies within the overall check zone, this feature is operative. Also, being identical to the main protection in design and execution the check feature is as fast as the main feature. Finally both features are physically independent which makes this the ideal form of check features. **Costwise** also, this is not an unattractive proposition, and is therefore recommended whenever possible.

The check contact is invariably recommended in the negative lead of the tripping relays, shunted by a resistor of appropriate value as shown in Fig. 30. This would prevent the trip relays getting energised when and if the positive gets applied to the relays inadvertently as could very well happen in the cable trenches during testing. The resistor across this contact takes care of the corrosion problems.

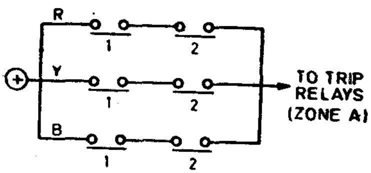
6.2.2.3 *Checkfeature using two differential relays in series (relay duplication)* — *This is* comparatively a less than ideal solution since the current transformers feeding both the relays are the same. The duplicated relays can be connected to the bus wires in two different manners, depending upon whether the relay is a high or medium impedance type.

For high impedance type relays (as defined in 5.2.8.2 and **5.2.8.3),** the two relays can be connected in parallel across each zone bus wires. Their contacts will then be connected in series as shown in Fig. 34A. The relays

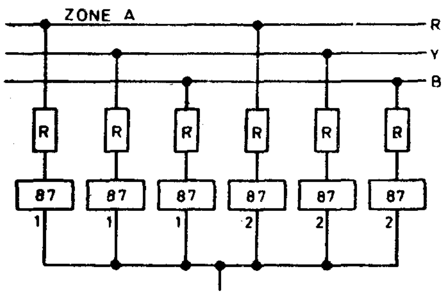
being high impedance type, connecting two in parallel does not increase the primary operating current of the protective system appreciably (*see* Fig. 34B).

The relay setting voltage can be worked out ignoring the presence of the second relay and both the relays can be given the same current settings.

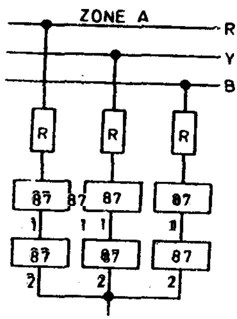
For relays of the medium impedance type (*see* **5.2.8.1**) connecting the two relays in parallel is not advisable for the fear of the primary operating current (POC) being adversely affected. The solution is to connect the two relay elements in series, with a single common stabilising resistor as shown in Fig. 34C. Again both the relays are given the same settings and



34A Relay Contacts in Series



34B With High Impedance Relays



34C With Medium Impedance Relays

87 — Relay
1, 2 — Relay Contacts
R — Resistance

FIG. 34 CHECK FEATURE BY RELAY DUPLICATION (TYPICAL)

the stabilising resistor value can be worked out from the following formula for a given voltage setting:

$$V = i_r (R_s + 2R_r)$$

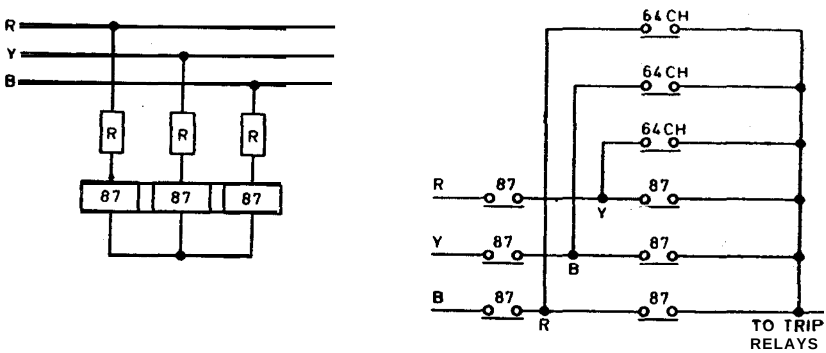
where

V = *voltage* setting,
i_r = setting current (same for both the relays),
R_s = stabilising Resistor value, and
R_r = relay impedance at setting current i_r.

6.2.2.4 *Check feature with inherent phase fault and external earth fault check* — This is indicated in Fig. 35. When there are three differential relays, one for each phase, two of them will and should operate for a phase fault. Hence by merely connecting the relay contacts two by two in series as shown in Fig. 35, an inherent phase fault check results.

A separate earth fault check relay, described in 6.2.2.5 and 6.2.2.6 can be added, and its contacts can be connected.

6.2.2.5 *Earth fault check relay, zero sequence voltage operated* — This is a sensitive instantaneous overvoltage relay with low settings energised by the open-delta voltage of a bus-connected voltage transformer. When an earth fault occurs on bus bars there appears a zero sequence voltage across the open delta terminals which causes the relay to pick-up. When a solid phase-to-earth fault occurs on the bus bar the voltage that appears across the relay would be rated line voltage of the tertiary winding, assuming no arcing and a solidly-earthed system. However, arcing cannot be precluded altogether and a low setting of about 20 percent should be adopted for this relay, to ensure fast operation under such conditions.



64CH — *Earth* Fault Check Relay
87 — Differential Relay

Fig. 35 Built-in Phase Fault Check

When the main voltage transformers do not have a tertiary winding, a 1 : 1 ratio auxiliary voltage transformer connected star/open delta can be employed. Further when there are two or more main voltage transformers, one per zone, as many check relays will be required. Also fuses should be avoided on the secondary side of the auxiliary voltage transformer. The primary fuses can, however, be retained. Suitable switches to short-circuit the check relay contact when the check relay supply fails also have to be provided as required.

6.2.2.6 *Earth fault check relay, zero sequence cuwent operated* — Though most of the methods of connection of current transformers described under 5.13 can be adopted for outdoor installations also, the most common one is that using current transformers mounted in the transformer neutrals. However, it has'the disadvantage that it is not available when the transformers with earthed neutrals are kept disconnected from the bus bars.

When there are more than one transformers, a neutral current transformer is required for each, the secondaries of all such neutral current transformers being paralleled and connected to the relay. The relay can be a current operated type with a setting range of 10 to 40 of rated current transformer secondary current.

6.23 ***Secondary Wiring Supervision***

6.2.3.1 *Any* protective system which requires the balancing of secondary currents from two or more sets of current transformers over pilots depends heavily on the integrity of these pilots for correct operation. In a high impedance circulating current scheme, where the relay operation is closely associated with the magnitude of the voltage across the pilots at the relay terminals, an open-circuiting or short-circuiting of the leads of any one of the current transformers would seriously interfere with the performance of the protection. The effect of an open-circuited current transformer is the same as that of an internal fault. In such cases a voltage proportional to the primary current in the open-circuited current transformer. can appear across the relay. If this current is less than the primary operating current setting of the protection there may not be any danger, but a subsequent through fault can cause an unwanted trip. Similarly with a short-circuited pilot an internal fault can go undetected, depending upon the location of short circuit. It is therefore customary to employ some kind of secondary circuit supervision scheme to detect and alert the operational staff about such secondary wiring faults.

6.2.3.2 Continuous supervision by means of an externally injected alternating current through the test windings of the current transformers is one of the methods available though it is not popular because of the complications created for double bus bar installations. Further, with bushing mounted current transformers the provision of test windings imposes additional design limitations. Another method is to incorporate *a* millivoltmeter with a push button in the secondary winding.

The more popular scheme is the self powered one using the load current itself for the supervision. A very sensitive voltage operated relay is connected across the bus wires, in the same manner as the main differential relay. The relay is given a voltage setting such that for a given set of main relays and current transformers the primary operating current is 10 percent of the load current of the least loaded current transformer or 25A, whichever is higher. In practice, the load details are not exactly known and hence a figure of 25A is taken for calculation purpose.

The supervision relay is usually followed by timer relay with a range of 2 to 10 seconds, set to operate at about 3 seconds. The time delay helps to avoid unwanted alarms in the case of through faults as well as internal faults.

The supervision relay is also normally arranged to short-circuit the bus wires thereby affording thermal protection to itself (as such relays are not normally continuous rated) and also preventing unwanted tripping by the main protection, should a through fault occur further to its operation.

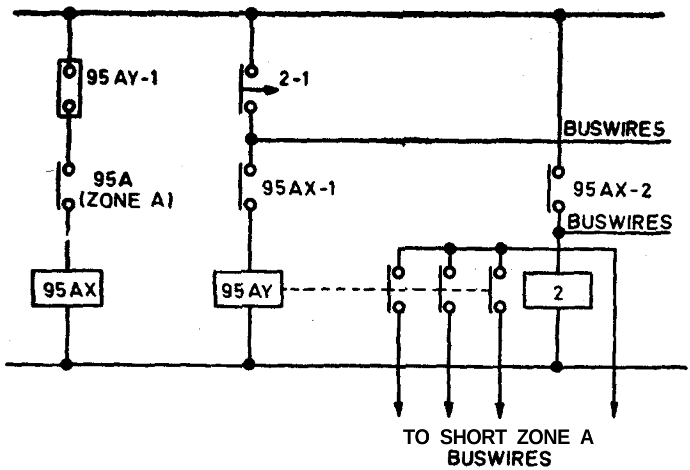
Where the supervision relays are not provided with built-in timer, a single external timer can be used with a protection scheme having more than one zone (and hence as many supervision relays). The method of connection is shown in Fig. 36.

The effectiveness of the supervision feature can be fully realised only if the bus fault-levels are high enough to adopt a comparatively high setting on the differential relays. If such is not the case, narrower margin between the settings of the main and supervision relays can result in themal-operation of the main relays, before the supervision relays get a chance 'to short-circuit the bus wires. Where such a narrow margin exists, the check feature is a must.

6.2.4 *DC Circuits for Selective Tripping* — The design of the dc tripping circuit should take into account all the checks built into the bus bar protection. Further, it should also ensure that all the circuits contributing to the flow of fault current should be tripped out with minimum delay. In double bus layouts the circuits are capable of being connected to more than one zone and the trip circuit should be arranged to have only the correct circuits tripped in the event of any one zone differential relay operation.

There are mainly two types of trip circuits employed which fulfil all these conditions .

6.2.4.1 *Type I trip circuits (using individual feeder trip relays)* — Here individual hand-reset trip relays are provided for each circuit and two such relays for bus couplers and bus section. The dc trip circuit is an image of the actual primary connection, as shown in Fig. 25B. The feeder trip relays are selected through the auxiliary switches of the isolator to dc bus wires of either zone *A* or zone *B*. The trip relays of bus coupler (and bus section, if any) are permanently connected to the dc bus bars, **one each,**



2 — Timer
95 — Supervision Relay of Zone *A*

FIG. *36* ARRANGEMENT OF SUPERVISION RELAYS AUXILIARY ELEMENTS WITH COMMON TIMBER FOR ALL ZONES (TYPICAL)

6.2.4.2 *Type II trip circuits (using multi-contact master trip relays)* -This arrangement is illustrated in Fig. 25C with only a single master trip relay for one zone. The trip selection is achieved in the circuit-breaker trip coil circuits again, with the help of isolator auxiliary switches (in the case of feeders). For the bus coupler (and bus section, if any) contacts of zone *A* and zone *B* master trip relays are connected in parallel without any selection arrangement.

6.2.4.3 *Comparison of the two types of trip circuits* — For large, important and likely-to-expand installations the type I circuit is to be preferred even though it may call for a large number of trip relays, for the following reasons:

a) It facilitates expansion. The usual practice is to mount the circuit trip. relay on the individual circuit panels, with bus bar protection panels accommodating only the differential relay, supervision relays and others which are common for the bus protection. Hence an addition of a circuit to the existing installation would not need any modification of the bus bar protection panel either by way of additional drilling or wiring.

b) Without the provision of a check feature, the type II trip circuit involves greater risk compared to type I arrangement in as much as a mal-operation of the trip relay can shut down the entire station.

c) With type I trip circuits the selection is not done in the trip coil circuit unlike in type II trip circuit. The latter therefore increases the cabling in the breaker trip circuit which is undesirable.

d) Type I trip circuit has the further advantage that regular proving test of the circuit tripping can readily include proving the tripping from the bus bar protection trip relay. But with multi-contact relay, such proving tests need careful consideration to avoid wrong tripping of circuits other than the one *being* tested.

6.2.4.4 *Other requirements of bus bar protection trip circuit design:*

a) The bus bar protection trip circuit should be separately fused and should not be connected with other tripping circuits. The wiring should be preferably separated from others and for this reason a separate panel as indicated in 6.2.4.2 is usually provided.

b) The trip and alarm supplies should be separately supervised and alarm for their failures should be provided.

c) Protection cut-off switches should be provided for each zone.

6.2.5 *Alarms and Indications*

6.2.5.1 The following alarms and indications should be generally included:

a) *Common Alarms*

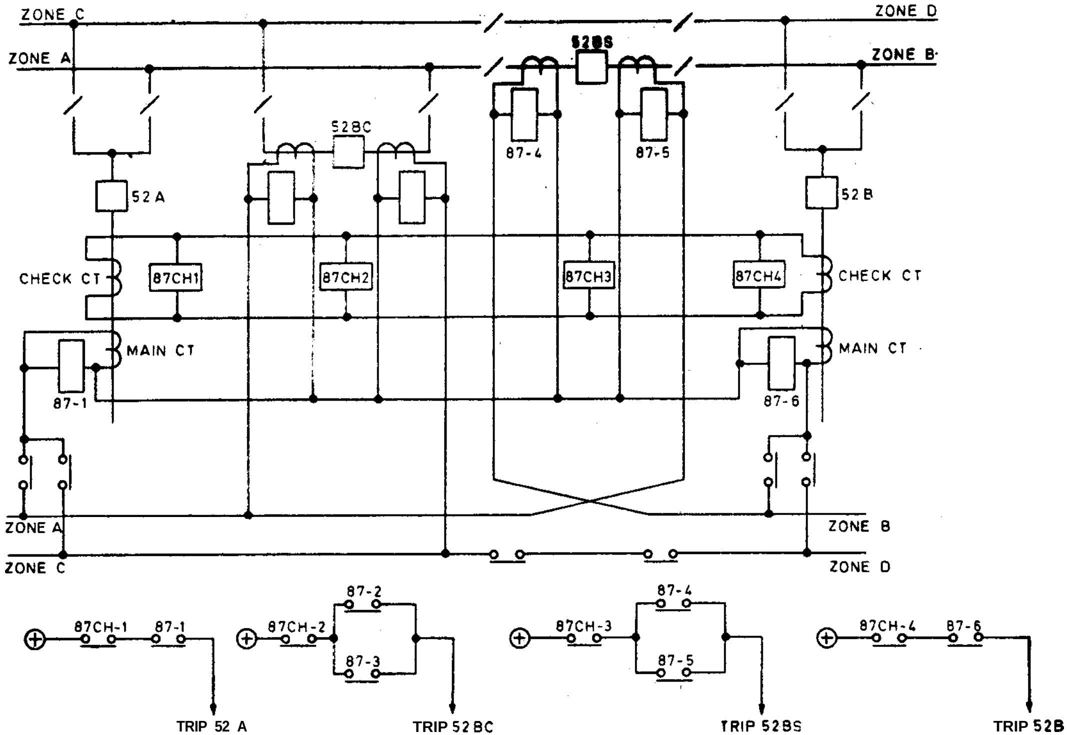
1) Bus bar protection defective	(audible $-visual)
2) Bus bar fault	do
3) Trip supply failure	do
4) Alarm supply failure	do

b) *For Individual Zones*

1) Zone operated	(audible+visual)
2) Zone in commission	(visual)
3) Zone out of commission	(visual)

6.2.6 *Scheme for Extra High Voltage (EHV) Installations* — This scheme is particularly suited to EHV substations (400 kV and above) where the distance between two circuit-breakers is great and it may be required to restrict the discharge capacitance of dc cabling on the battery. It would however require high impedance differential relays (as against medium impedance relays) whose operating current is only a few milliamperes. A typical scheme of connections is illustrated in Pig. 37.

It will be seen that each circuit has its own ac (high impedance differential) relay, the bus coupler and bus sections being provided with two each (in this respect the arrangement is similar to the ordinary scheme described earlier with type I trip circuits). Also each circuit has its own check relay. There are no dc trip relays and hence no dc trip relay selection using auxiliary switches is necessary. This results in considerable amount of saving of cabling between main control room and switchyard, which, in such large installations, more than offsets the cost of added high impedance relays.



CT — Current Transformer
87 — Differential Relay
87CH — Check Relay
5.2 — Circuit Breaker

FIG. 37 SCHEME FOR EXTRA HIGH VOLTAGE INSTALLATION (TYPICAL)

The scheme can be used in case the number of circuits are not large otherwise very high primary fault setting will result which may not be acceptable on systems when fault current is limited.

6.3 Application Problems

6.3.1 *Bypassing of* Circuits

6.3.1.1 In duplicate bus bar installations it is sometimes the practice to arrange for bypassing the circuit-breakers for maintenance purposes. Further, in the transfer bus layouts, such facility is always built-in. When a circuit is bypassed, the bus coupler will have to take over the control of the bypassed circuit including protection and tripping. From the point of view of the bus bar protection, the bypassing arrangement needs careful study.

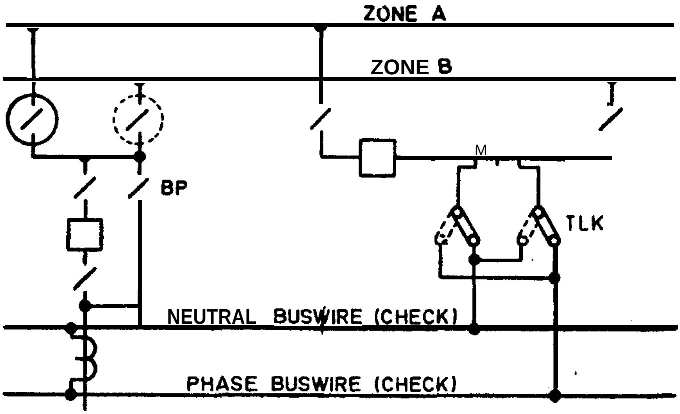
6.3.1.2 The following aspects of the bypassing arrangement have considerable bearing on the design and execution of the bus protection scheme :

a) *The type of bypassing arrangement* — If, under bypass condition, the secondaries of the current transformers on some of the circuits need reconnection/short-circuiting the same has to be done manually, using test links provided the bypassing is carried out using jumper connection. However, with isolators doing this job, their auxiliary switches can be advantageously used to do the switching of the current transformer secondaries.

b) *The degree of flexibility provided for bypass* — In double bus bar layouts if the bypassing can be done on to either of the bus bars, the switching required for the bus coupler current transformers would become slightly complex. This is illustrated in Fig. 38 where the manual switching using test link blocks is shown. Use of auxiliary contacts of the bypass isolators in this case will further complicate the matters.

c) *Location of current transformers* --The ideal location of the bus protection current transformers is outside of the zone of bypass **and this location** should always be chosen, unless the breaker is bulk **oil type, with bushing mounted** current transformers.

   From consideration of minimum amount of current transformer secondary reconnection, a bypass arrangement where the current transformers are located outside the zone of bypass and where the bypassing is always done only to one of the bus bars (say, the duplicate bus bar) is the ideal one. These reconnections can be attempted manually, using the test link blocks or automatically (wherever possible) using auxiliary switch contacts. In either case, wherever a current transformer is to be disconnected altogether, it should first be short-circuited, to avoid any inadvertent damage. Thus, special test links which can make before break or auxiliary switches which can break before make, should be employed for this purpose.



NOTE 1 - Link position shown is for feeder bypassed on to Zone A (full-circled isolator closed).

NOTE 2 — Dotted position for feeder bypassed on to Zone B (dotted-circled isolator Closed).

BP — Bypass Isolator
TLK — Test Links

FIG. 38 METHOD OF SWITCHING THE CHECK ZONE CURRENT TRANSFORMERS ON BUS COUPLER, WITH DUAL BYPASS FACILITY (TYPICAL)

6.33 *Cabling* — In high impedance scheme, it is very essential to plan the layout of the cabling for current transformer interconnection in the switchyard carefully in order to get the best performance from the scheme. The cabling should aim at reducing the lead burden of the current transformers to the minimum, the lead burden, in this case, being defined as that contributed by the loop impedance between the current transformer secondary terminals and the point at which the relay is to be connected. This can be reduced considerably by the following precautions:

a) Instead of bringing all current transformer leads to the relay panel before paralleling and connecting to the relay, a set of such paralleling bus-wires should be formed in the switchyard, between marshalling kiosks of each circuit. From a suitable point, which is the stub, connections for the relay should be tapped, this point being such that it results in the smallest lead length between it and the farthest current transformer.

b) The leads from the current transformer terminal boxes should terminate in the test link block mounted in the marshalling kiosk of the associated circuit. From there, they should be routed through the isolator auxiliary switches (if selection is required) back to the marshalling kiosk before forming the paralleling bus wires mentioned above.

c) When relays are used to switch current transformer secondaries due to, say lack of enough number of contacts on auxiliary switches, it is preferable to have such relays located right at the switchyard.

If for some reasons, this practice of cabling is not followed, it has to be ensured that the cable size is suitably increased to reduce the burden between current transformers and relays.

7. OTHER TYPES OF BUS BAR PROTECTION

7.1 Apart from the types of protection discussed so far which are most common, the following types are also sometimes used:

a) Directional comparison relaying,

b) Bus transformer differential relaying,

c) Phase comparison relaying, and

d) Distance protection.

However, IS their use is very limited, these are not covered in this guide.

8. SETTING CALCULATIONS FOR PRACTICAL INSTALLATION

8.1 For the practical installation (typical) shown in Fig. 39 the calculations for arriving at the various settings are as given below:

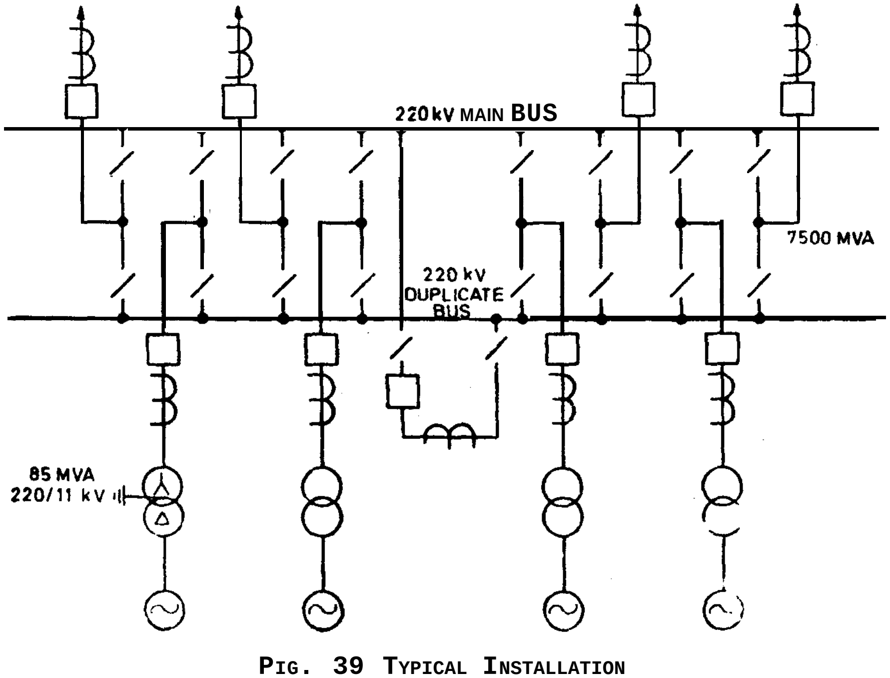


FIG. 39 TYPICAL INSTALLATION

a) *System* — *220* kV, solidly earthed,
b) *Switchgear breaking capacity* — *7 500* mVA at 220 kV,
c) *Normal load on each feeder* — *250* A,
d) *Maximum load on any circuit* — $1 \cdot 5 \times$ Normal rating,
e) *Current transformers ratio*—800/1 A (for magnetising curve, *see* Fig. 40),
f) *Lead length (between marshalling kiosk and fault current transformers)* — 100 m (one way),
g) *Leads* —*7/·029 (cu),* resistance at 20°C being 5·9 ohms/km,
h) *Relay burden* — 1 VA at setting,
j) *Relay setting range* — *20* to *80* percent of 1 A,
k) *Supervision relay burden* — 2·3 mVA at setting,
m) *Supervision setting range* — *2* to 14 V,
n) *Maximum number of circuits/zones under normal working:*
   i) *Main zones* — *5* (inclusive of bus coupler)
   ii) *Check zones* — *8*
p) *Metrosil characteristics* — $V_{peak} = 900\,(I_{peak})^{0 \cdot 25}$.

8.2 Calculations

8.2.1 *Through Fault Stability Limit* — Maximum through fault primary current I_f (based on switchgear breaking capacity) = $\dfrac{7\,500 \times 10^6}{\sqrt{3} \times 220 \times 10^3}$

= 19700A

The secondary equivalent $I_f = \dfrac{19\,700}{800} = 24 \cdot 6$ A

8.2.2 *Relay Setting Voltage:*

$R_{CT} = 2.73$ ohms

$R_L = 0 \cdot 59$ ohms (for 100 metres)

Therefore, relay setting voltage = $I_f \times (R_{CT} + 2R_L)$

$= 24 \cdot 6\,(2 \cdot 73 + 0 \cdot 59 \times 2) = 96$ V.

The relay can therefore be set for 100 V. Also the current transformers have *a* knee-point voltage of 302 V (from Fig. 40) which is more than twice the setting voltage above. Hence they are adequate.

8.2.3 *Relay Setting Current* — *This* should be chosen, based upon the permissive maximum primary operating current of the protection. The primary operating current should not be more than 30 percent of the minimum fault current. Also it should he higher than maximum load encountered on an): feeder (say 125 percent of maximum load).

Taking the latter figure, the primary operating current should be not less than 1·25 x 250 x 1·5 = 470 A.

The exciting current drawn by the current transformer at relay setting of 100 V = 11·3 mA (from Fig. 40).

The current drawn by metrosils (if any is required) is given by

$$\sqrt{2} \times 100 = 900 \cdot I_p^{0 \cdot 25}$$

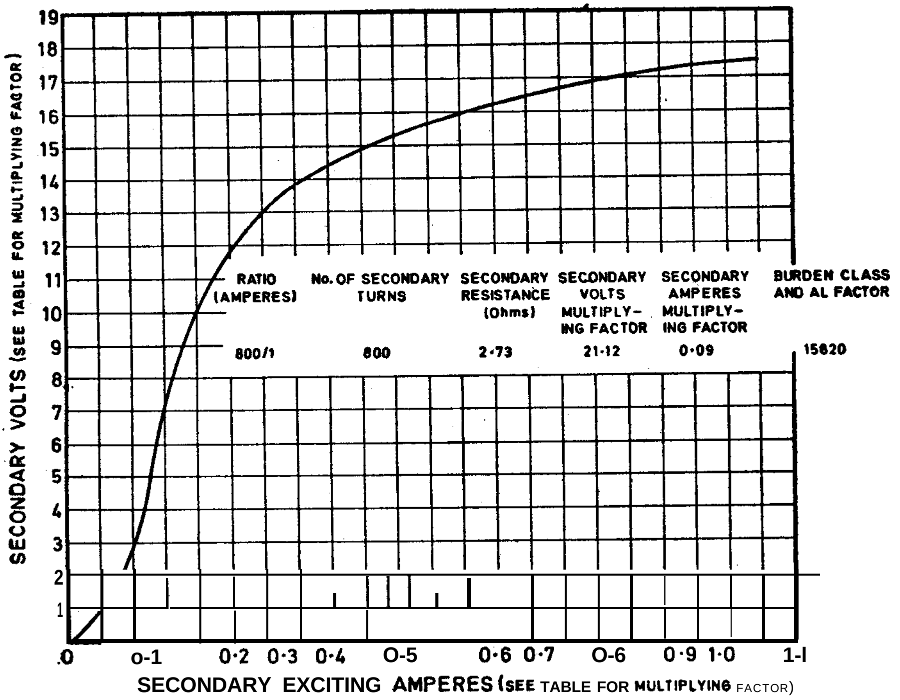


FIG. 40 MAGNETIZING CURVE FOR CURRENT TRANSFORMER (TYPICAL)

Therefore, or I_p = 0·43 mA.

8.2.3.1 *The main zones*

$$\frac{\text{Primary operating current}}{\text{Current transformer ratio}} = I_R + n \, . \, I_{mag} + I_{metrosil}$$ (neglecting the current drawn by supervision relays).

Therefore, $\frac{470}{800} = \left(I_R + \frac{5 \times 11\cdot3 + 0\cdot43}{1\,0\,0\,0}\right)$ where I_R is in A

Therefore, $I_R = 0\cdot53$ A

The nearest higher setting is 0·6 A (60 percent)

The corresponding primary operating current

$$= \left[0\cdot6 + \left(\frac{5 \times 11\cdot3 + 0\cdot43}{1\,000}\right)\right] 800 = 527 \text{ A.}$$

8.2.3.2 For check feature with the same current setting on the relay,

$$\text{Primary operating current} = \left[0{\cdot}6 + \left(\frac{8\times 11{\cdot}3+0{\cdot}43}{1\ 000}\right)\right] 800 = 552\ \text{A.}$$

8.2.4 *Stabilising Resistor Setting (For both Main and Check Zones)*

Setting voltage = 100 V

$$\text{Total shunt impedance required} = \frac{100}{0{\cdot}6} = 167\ \text{ohms}$$

$$\text{Relay impedance at setting} = \frac{1}{(0{\cdot}6)^2} = 2.78\ \text{ohms}$$

Hence stabilizing resistor value = 167—2·78 (say, 164 ohms).

8.2.5 *Metrosils (For both Main and Check Zones)*

Peak voltage during internal fault is given by

$$V_p = 2\sqrt{2}\ \sqrt{V_k\,(V_f - V_k)}$$

where

V_k = knee point voltage

$V_f = I_f \times$ relay branch impedance

$= 24{\cdot}6 \times 167 = 4\ 100$ V

V_k = 302 V (from magnetising curve, see Fig. 40)

$$\therefore\ V_{peak} = 2\sqrt{2}\ \sqrt{302\,(4\ 100 - 302)} = 3\ 030\ \text{V (that is } 3{\cdot}03\ \text{kV)}$$

Hence metrosils are required.

8.2.6 *Supervision Relay Settings* — Taking the primary, operating current as not less than 25 A. We have the secondary equivalent current,

$$= \frac{25}{800} = 31.25\ \text{mA}$$

This would be shunted by:

a) the current transformers;.

b) the differential relay branch;

c) the metrosils; and

d) supervision relay itself, depending upon the voltage setting adopted on the supervision relay. Choosing the latter as 5 V for the first set of calculations we have the following:

1) The magnetizing currents drawn by the current transformers (from Fig. 40) = 1·35 mA,

2) The differential relay branch current $= \dfrac{5\times 1000}{167} = 30$ mA,

3) The metrosil current at this voltage will be negligible,

4) The current drawn by supervision relay itself

$$= \frac{2{\cdot}3}{5}\ \text{mA} = 0{\cdot}46\ \text{mA.}$$

8.2.6.1 *For main feature*

Effective primary operating current $= \dfrac{800\,(1.35 \times 5 + 30 + 0.46)\ \text{A}}{1000}$

$= 30$ A (approximately).

8.2.6.2 For check feature

Effective primary operating current $= 800\,\dfrac{(1.35 \times 8 + 30 + 0.46)}{1000} = 41$ A

Hence 5 V setting on supervision relay is adequate.

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